



Final Design Review
Solar Decathlon Competition 2021

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Team:
Solar Decathletes

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CHANGE LOG

Below are all changes that we made throughout the document over the course of the project. All requests for changes are documented below as well as corrections and additions:

Table 1. Change Log

Report Section #	Source of recommended edit (Sponsor, Advisor, Team, Reviewer)	Brief description of edit
1	Advisor	Added in additional information about the competition and updated design choices
Prior to 1	Advisor	Added in list of figures and tables on separate pages after table of contents
2	Advisor	Added competition specifics and interviews
All	Advisor	Started page numbers after table of contents and ended them before appendices
All	Advisor	Numbered references in order that they appear
All	Advisor	Made each section start on a new page
Title Page	Advisor	Added mechanical engineering logo, sponsor information, and other minor details
5	Advisor	Added in section for concept prototype
2	Team	Addition customer information added about selected site.
3	Team	Customer needs/wants update to reflect attached housing division
3	Team	Engineering specifications updated to reflect attached housing division
6	Team	Conclusion updated to reflect PDR
Prior to 1	Advisor, Team	New team member and partner updates
5-9	Advisor, Team	Addition of sections to reflect CDR
5-9	Advisor, Team	Modification of sections to reflect FDR

EXECUTIVE SUMMARY

This report is intended to outline all relevant background information, decisions, and design direction for our senior project at California Polytechnic State University, San Luis Obispo. We will be designing net-zero, affordable housing to compete in the attached housing division of the 2021 Department of Energy Solar Decathlon. With the increased urgency of climate change and focus on sustainability in construction, the importance of designing a net-zero structure is very apparent. Because there is a great need for affordable and sustainable housing in Watts, CA, we will be tailoring our design to meet this community's needs. Details of the Solar Decathlon competition, the need for sustainable, affordable housing, and the various mechanical systems such as, plumbing, HVAC, and power systems are detailed below in the body of the report. Additionally, the process of creating the initial concept design is outlined as well.

1. INTRODUCTION

We are a group of five mechanical engineering seniors at California Polytechnic State University, San Luis Obispo competing in the 2021 Solar Decathlon put forth by the US Department of Energy as our Senior Project. We are also joined by three students from the Architecture department, two students from the City and Regional Planning department, and one student from the Construction Management department. This annual competition challenges students to design a net-zero structure in one of seven divisions: suburban single-family, urban single-family, attached housing, mixed-use multifamily, elementary school, retail building, and office building.

As we design a high-performing net-zero building, we must integrate the building science principles and best practices for the building envelope and mechanical systems. This design challenge evaluates our project across ten separate contests: architecture, engineering, market analysis, durability and resilience, embodied environmental impact, integrated performance, occupant experience, comfort and environmental quality, energy performance, and presentation. Our design must be an original design, an improvement of a new design for a Design Partner, or a retrofitting of an existing building. In addition, local, state, and national codes or standards governing topics such as fire protection, ADA requirements, seismic requirements and other specifics must be considered as we are developing the structure.

Our team's interest lies in creating affordable and compact housing for low-income individuals within Los Angeles County. We originally decided to design an urban single-family home in empty government owned lots within the county. This housing unit would serve as transitional housing dedicated towards aiding those who have been experiencing homelessness in the city. However, upon further research and consultation with architecture students and professionals, we decided to modify our project scope and pursue the design of an attached housing building with a daycare. This housing will be tailored towards working single guardians in the Watts area. This report details the necessary background information, scope of our project, and our process to accomplish this.

We have interviewed several professionals and experts on various aspects of the structure. We spoke to Lawrence Sun, a Mechanical Engineering professor at Cal Poly who specializes in HVAC systems and has decades of experience in the industry. He discussed the possibility of using a geothermal heat pump and explained the basics of selecting a residential HVAC system. We connected with Jason Freeman, a sales engineer at DMG, to select the mechanical equipment of our building. We also met with Margaret Kirk, a former architect and professor of Architecture at Cal Poly. She has experience with building small urban housing and offered us advice about selection of location, zoning codes, and structure of our design process. Hisham Assal provided us with information about an existing sustainable house in our area as well as information about how building codes would affect our design process and analyzing energy impact. Additionally, we met with Jacques Belanger, a Cal Poly Mechanical Engineering Professor with decades of experience in the renewable energy industry. He advised us to focus on solar photovoltaic power systems rather than solar thermal due to its increasing affordability and guided us in our energy consumption and production calculations.

2. BACKGROUND

2.1 CUSTOMER NEEDS

There is a great need for affordable housing in California. 27% of the United States' homeless population resides in California. Homelessness in this state increased by more than 22% over the last decade. Between 2018-2019 alone, homelessness increased by over 16%. Most of this strain occurs in the major cities, like Los Angeles or San Francisco. Rent burden is defined by renters spending more than 50% of their household income on rent; major California cities have higher rates of severe rent burden than the average United States metropolitan area. As of 2019, California is experiencing a shortage of 1.4 million affordable homes [1]. According to the California Poverty Measure in 2018, about 18% of families lacked resources to meet their basic needs due to a low annual income of about \$35,000 [2].

Watts, California is a neighborhood of Los Angeles located in South Central Los Angeles. It faces several social and economic issues and has historically experienced significant periods of unrest. It has one of the highest population densities of the county at 17,346 people per square mile, very low household income at a median of \$25,161, and very low rates of higher education among residents with about 2.9% of residents older than 24 having a four-year degree. Importantly, it also has one of the highest rates of single parentage, with 38.9% of families being headed by a single parent [3]. This puts significant strains on the already stressed community.

The community in Watts also faces issues with affordable housing. In recent years, Los Angeles County has experienced a significant housing shortage, driving up rent prices. The area has seen a surge in jobs since recovering from the 2008 recession, but this has not been matched with a surge in housing construction. This particularly impacts lower-income neighborhoods and leads to displacement of these individuals. Between 40% and 50% of households spend at least half their income on rent, as seen in the map seen in Figure 1 [4].

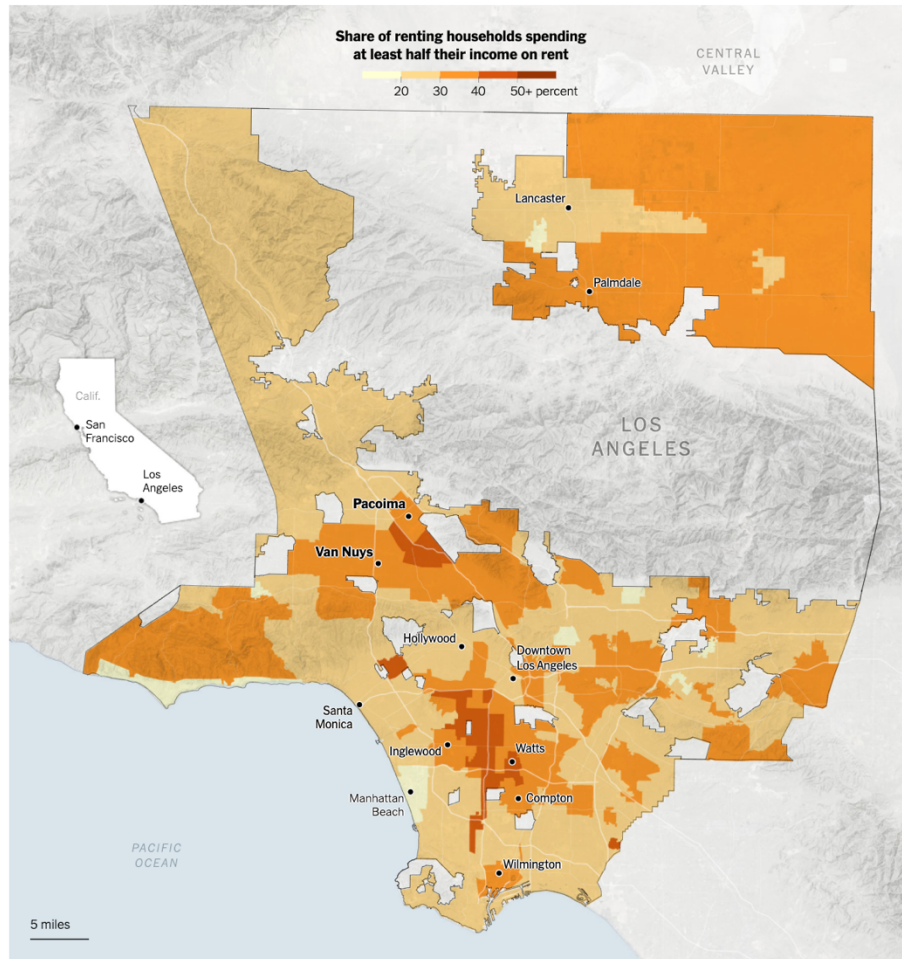


Figure 1. Map of Los Angeles County Depicting Affordable Housing Crisis

In 2015, California passed the Clean Energy and Pollution Reduction Act, also known as Senate Bill 350. This bill outlines clean energy, clean air, and greenhouse gas reduction goals [4]. Even though more than 50% of all California homes have central or room air conditioning, air conditioning is a very small overall contributor to energy consumption. As seen from Figure 2 below, space heating, water heating, and appliances, electronics, and lighting make up a majority of California's energy consumption [5]. To reach the clean energy, air, and greenhouse gas reduction goals outlined in SB 350, California needs more homes using renewable energy rather than natural gas, ethically and responsibly sourced construction materials, and more energy efficient temperature control methods. To see the breakdown of California's energy usage, refer to Figure 2.

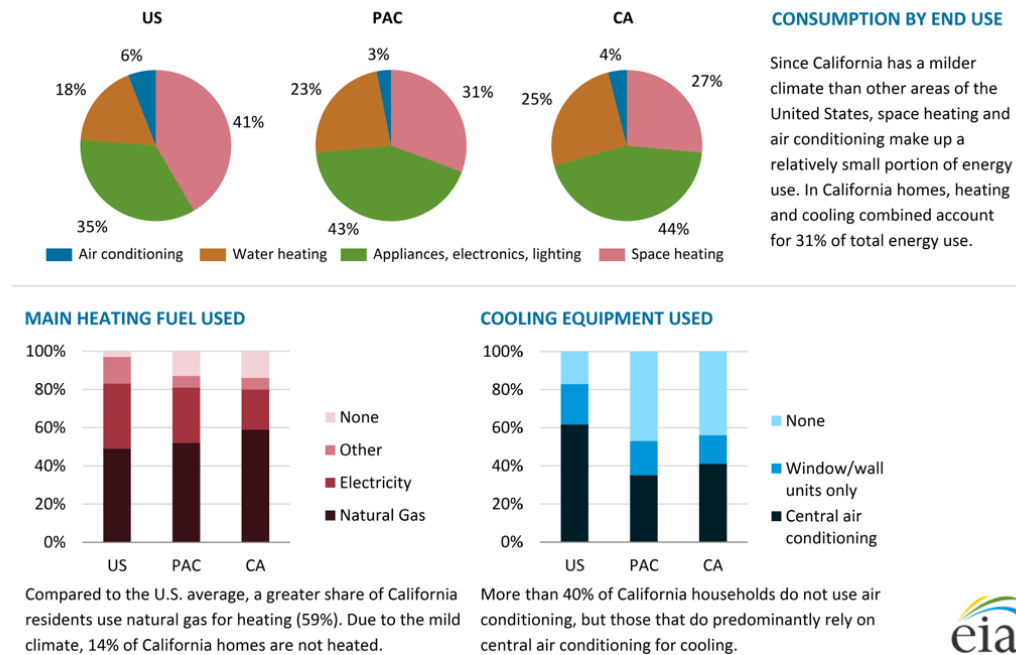


Figure 2. Graphics Describing Consumption by End Use

2.2 MECHANICAL SYSTEMS

The Heating, Ventilation, and Air Conditioning (HVAC) systems of a residential building account for about half of a structure's total energy consumption [6]. Therefore, the decisions made regarding this system will be a major concern during the design process. Given that the building should be net-zero, HVAC systems that utilize renewable energy without drawing significant power from the main power supply would be advantageous. These systems include geothermal heat pumps and absorption cooling systems. Geothermal heat pumps, also known as water-cooled systems, operate very similarly to the traditional air-cooled HVAC systems. However, instead of rejecting heat to the air they reject heat through underground pipes installed beneath the structure or in the yard [7]. Absorption cooling systems use large amounts of thermal energy input to power a generator and absorber, rather than a small amount of high-grade mechanical energy to power a compressor. These allow for the use of solar energy usage but are more expensive and require more space for the additional piping and components of the system [8]. Although these systems offer creative solutions for our net-zero design, they are newer in the field of HVAC and tend to be more expensive than traditional air-cooled vapor compression systems.

One of the many HVAC systems that could be used to minimize the load is a ductless mechanical system which have become more popular in the market. There is a great energy saving potential in using a ductless system. It allows for space-by-space heating and cooling, allowing energy consumption to decline by conditioning necessary spaces only. Additionally, fewer losses are experienced in this system since air will not leak out of ductwork. A study conducted on 24 homes with ducted systems in California discovered that the thermal delivery efficiency is about 64% [9]. Through the study, researchers discovered that ductless systems with the same efficiency could reduce the HVAC energy consumption by about 20% [9]. Although HVAC energy consumption is decreased, ductless split systems have a higher initial cost. The placement of these systems is also crucial to the efficiency of the system; if it is installed in cooler climates, backup heating is required.

The National Institute of Standards and Technology conducted research on various types of HVAC systems comparing the energy, comfort, and performance of commercially available HVAC systems. Through the research, the most efficient system with a net zero outcome was an air-source heat pump with a heat recovery ventilation. This would decrease the amount of energy used to bring the outdoor air temperature to match the ambient room temperature.

To achieve net zero housing, building energy demand must be minimized and on-site renewable energy generation must be maximized. Although the different types of HVAC systems mentioned above are important for net-zero housing, the appliances, controls, and occupant behaviors are crucial to the net amount of energy consumed in the home. Optimizing gains and losses by utilizing the climate through passive design strategies is the best approach for low-cost, net-zero housing. Specific criteria to focus on are thermal insulation, airtightness, optimized orientation and shape, and solar shading.

2.3 PLUMBING

Sustainable plumbing systems will be utilized in the design of this structure. The key considerations in the design of sustainable plumbing are energy efficiency, sustainable or recycled materials, and water efficiency. The use of components that utilize less energy will improve energy efficiency. Using sustainable or recycled materials is more difficult in plumbing systems than in other aspects of construction but can be done to a certain degree. For example, it is possible to obtain recycled copper piping or plastic piping that has recycled lining. Water efficiency of a system can be achieved by choosing components that consume less water as well as introducing components to recycle water [10]. The field of water efficient technology, such as shower heads, sinks, dishwashers, and washing machines, has been expanding in recent years due to a shifting focus in the industry towards sustainability. Therefore, there is a wealth of water-saving options currently on the market [12].

One sustainable method to reuse water in a household is by implementing a greywater system. An average California resident uses 85 gallons every day, so adding in a greywater system could help conserve water [13]. Greywater is categorized into two loads: low-load, originating from showers, bathtubs, hand washbasins, and high-load, originating from washing machines [12]. The idea behind a greywater treatment is to recycle the water from these sources to mulch basins and other types of irrigation needs. Because reclaimed water is being used, it is important that the greywater fulfills four criteria: hygienic safety, environmental tolerance, economic feasibility, and no loss of comfort to the users [14].

2.4 POWER SYSTEMS

Solar panels will be installed on the roof of the home we design or on the surrounding land. There are two kinds of solar power generation systems: photovoltaic (PV) and thermal. In a commercial setting, concentrated solar thermal systems, or CSP, use the radiation from the sun to heat up a fluid (typically water or air), which drives a heat engine and electric generator to produce AC power [15]. For residential settings, they are used to heat water for homes. CSP systems store energy by using thermal energy storage technologies. CSP systems take up less roof space than PV systems because of their superior efficiency converting energy. CSP systems convert about 90% of the radiation it receives into heat energy, whereas PV cells convert about 15-20% of the radiation to electricity [16]. Photovoltaic solar panels rely on the photovoltaic effect to generate DC power. Usually, this DC power gets converted to AC using inverters. Due to the photovoltaic cells producing power directly from the sun's radiation, it is much harder to store the energy compared to CSP [15]. California has adopted a "net-metering" policy allowing solar PV owners to sell excess electricity back to the grid. This allows for homeowners to potentially make money on days where they produce more energy than they consume.

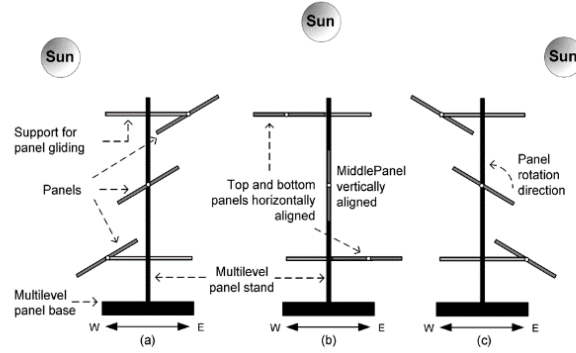


Figure 3. Arrangement of Solar Panels for Various Sun Positions

There are many kinds of solar thermal systems with a variety of uses. Solar water heaters are a cost-effective way to produce hot water and can be used in any climate. The two kinds of solar water heaters are active solar water heating systems, which use pumps to move water through a home, and passive heating systems. Based on the California climate, the active system most useful is the direct system. Direct active circulation systems circulate water through the collectors to heat the water and distribute it through the home. This design is good for warm climates, where the water has little chance of freezing. On the other hand, passive systems are less expensive, last longer, and can be more reliable than active systems [17]. Solar thermal panels may also be combined with other energy saving methods to drastically reduce household energy consumption. In Spain, radiant surface conditioning systems were combined with solar thermal panels and solar cooling systems for residential homes to reduce the annual energy demand by 69.47% [18].

Photovoltaic solar arrays also have a wide variety of designs and uses. To maximize the amount of solar power generation in crowded cities, there was a multilevel solar panel system designed in India shown above. This design minimizes the floor area of the panels. By shifting each panel horizontally by half the panel width, the panels on the lower levels do not get shaded by the ones above them. This design harnesses 18.6% more energy and has 33% less area than a conventional 3 fixed panel array [19]. An improved four-module reconfigurable PV array-based water-pumping system was developed for rural areas in 2018. The four panels are connected to a switch network that arranges the panels in any of the three configurations depicted in Figure 4 based on the operating conditions. This reconfigurable PV array, or RPVA, produced about 33% more energy and increased pumping time by two hours when compared to other PV pumping systems. This RPVA design is highly reliable for areas without energy storing capabilities [20].

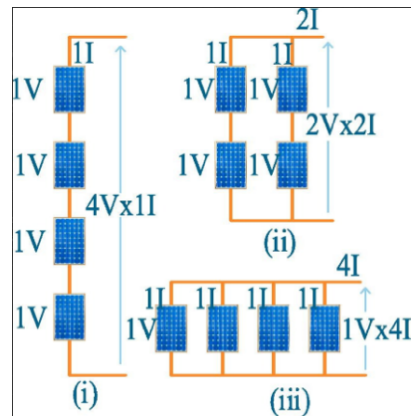


Figure 4. Three Configurations of PV Pumping System

After speaking with Jacques Belanger, we were advised to use solar PV for our home rather than solar thermal due to the government incentives, lower initial cost, and wider range of use. The federal solar tax credit, or investment tax credit, reduces the amount of income tax a person pays at the end of a tax year by 22-30% of the total cost of installation of a solar PV system between January 1, 2006 and December 31, 2021. Expenses applied to the tax credit include costs for the panel themselves, contractor labor costs for preparation and assembly, inspection costs, energy storage devices, and balance-of-system equipment including wiring, inverters, and mounting equipment []. Given that California has one of the highest income taxes in the nation, this tax credit is a huge benefit to installing solar PV. Though solar thermal systems have such a high efficiency compared to solar PV, they have a lot of system components that add to initial cost like pumps, water storage tanks, valves, and piping []. The multitude of system components adds a layer of complication to any maintenance needed for the system. On the other hand, solar PV systems are much simpler, containing only the solar panels, mounting structures, and inverters []. Due to its simplicity, the only maintenance required with solar PV is occasional cleaning of the panel surface when it gets dirtied. In addition, solar thermal systems can only be used to heat water in a residential setting, whereas solar PV can be used to generate electricity for the entire house, including water heating. Ultimately, solar PV technology is what we will focus on for our building.

2.5 BUILDING ENVELOPE

The envelope of the building is the complete structure that separates the indoor from the outdoor areas. This includes walls, floors, roofs, windows and doors, and the insulation of the building. A high-quality building envelope is essential to limiting heat gain and losses as well as indoor air quality. The best way to create a sustainable, net-zero energy building is to use the least amount of energy as possible. This increases the need for a carefully considered and efficient building envelope because it can dramatically reduce the amount of energy needed to provide a comfortable living space with superior indoor air quality. If the building envelope is not efficient, extra mechanical systems and energy are required to condition all the indoor spaces. Our design will utilize as many passive systems as possible to meet most of the passive home standards set by the Passive House Institutes, US (PHIUS). Passive buildings are intended to maximize energy efficiency by employing a myriad of industry tested building science techniques. These include continuous high-level insulation with no thermal bridging, extremely airtight building envelopes to prevent loss of conditioned air, use of high-performance windows and doors, management of solar gain, and the deployment of high-tech ventilation systems. The purpose of these measures is to reduce the need for space conditioning systems that are often very expensive and require a lot of energy.

Buildings built to the passive house standard typically cost 5-10% more to build than a conventional western house to current building standards. Although the cost of building is increased, it is usually paid back in time in the form of lower energy and maintenance costs, due to much smaller and simpler mechanical systems. Passive houses rely heavily on ventilation systems to circulate moisture and heat throughout the building. With effective insulation and airtight envelope, it is possible to heat and cool the entire house with small heat pumps [24].

In urban environments, the massive collection of buildings, paved areas, and human activity cause a phenomenon called urban hot spots or heat islands, where the temperature in the city can reach as much as 22 °F higher than the surrounding area [25]. To reduce these effects, it is important to increase the solar reflectance and vegetation cover of buildings. This can be achieved through “cool roofs.” Techniques to employ cool roofs include applying cool roof coatings consisting of white or reflective pigments, using roofing materials with increased reflective properties, or planting green roofs [26].

Traditional framing of houses is the most common type of construction method. Because it is the most well-known method for building, there is no need for specialized training for contractors, specialized equipment, or specialized facilities. This type of construction is done completely on-site by building the framing first, then installing insulation, electrical and HVAC systems, and oriental details. Although it is the most common method of construction, it can be difficult to achieve the airtightness and insulation values needed for passive home designs. Another downside to this type of construction is that the durability can suffer due to exposure of the framing during construction. Structurally insulated panels (SIPs) are a framing method that has been developed to decrease on-site construction time by simplifying assembly and provide very high levels of insulation while eliminating thermal bridging.

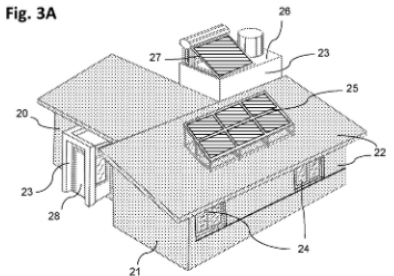
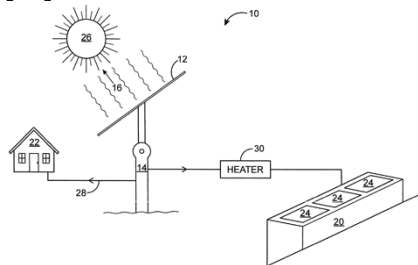
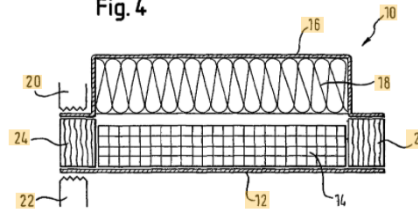
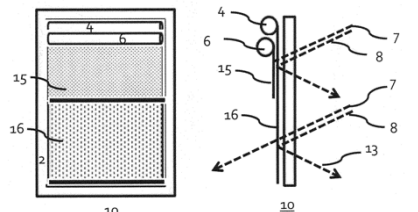
SIPs are panels of foam insulation sandwiched between sheets of plywood that are fabricated off-site and then assembled on-site. This method of construction provides high levels of insulation and airtightness, with quick assembly times. The downsides are the need for specialized facilities for panel fabrication as well as special training for installation of plumbing, electrical, and HVAC systems.

Insulated concrete forms (ICFs) provide excellent thermal insulation, airtightness, sound isolation, and durability. This construction method involves assembling the outer structure of the building with specialized foam blocks. Once the blocks are in place, concrete is poured into the blocks to form the walls. This leaves a concrete wall with foam insulation of both the inside and outside. While this type of construction provides great thermal properties, it can be difficult to waterproof and there are concerns with the environmental impacts of concrete. [27]

2.6 TABLE OF PATENTS

The patent research conducted is based on ways to save and utilize energy to maximize efficiency. All of the patents that were researched are relevant to our design because these are design decisions we will need to make after finalizing the design aspects of the project. The bio-climatically adapted zero-energy prefabricated modular building gave us inspiration when we were designing a house in the single-family urban housing division. The modular housing idea from this patent would allow for cheaper and quicker construction and it would drive us to create a more efficient structure. The photovoltaic phase change battery system was another interesting idea of converting energy. The phase-change system can be a method on creating energy within our housing structure. The panel with a vacuum element for out wall constructions would be a strategy used for the building insulation. If the insulated panels have efficient heat transfer, then it lessens the amount of energy needed for the HVAC system because we would be utilizing more passive systems. Lastly the energy efficient shading system is the most practical patent feasible to our design. This variable shading system would allow us to set the blinds to maximize efficiency during various times of the day.

Table 1. Results of Patent Search

Patent Name and Image	Patent Description	Patent no.
<p>Bio-climatically adapted zero-energy prefabricated modular building and methods thereof [26]</p> <p>Fig. 3A</p> 	<ul style="list-style-type: none"> • Prefabricated modular housing • Highly efficient building envelope to achieve thermal isolation from environment • Powered by renewable energy generator system 	US10767363
<p>Photovoltaic-phase change battery system for converting intermittent solar power into day and night electric power [27]</p> 	<ul style="list-style-type: none"> • Photovoltaic array pointed towards sun during daytime operation • Portion of electricity produced in day converts pool of phase change material to a molten state • PV array pointed at phase change material receives photons from thermal radiation, electricity generation continues 	US10594249B1
<p>Panel with a vacuum element for outer wall constructions [28]</p> <p>Fig. 4</p> 	<ul style="list-style-type: none"> • Vacuum insulated panel (VIP) for construction of outer walls in buildings • Obtains high thermal resistivity with slim profile • Consist of a plate-shaped, pressure-stable core material, which consists of compressed powder, glass fiber or open-cell plastic foams 	EP1436471B1
<p>Energy Efficient Shading System for Windows [29]</p> 	<ul style="list-style-type: none"> • Four selectable states providing independent control of lighting and heat into the space • Energy star guidelines implemented to set the performance levels for maximum efficiency 	US9850705B2

3. OBJECTIVES

The Department of Energy's Solar Decathlon competition will have ten separate challenges our design will be evaluated on and encompasses the idea of designing a high performing and energy efficient building. The evaluation criteria are Architecture, Engineering, Market Analysis, Durability and Resilience, Embodied Environmental Impact, Integrated Performance, Occupant Experience, Comfort and Environment Quality, Energy Performance, and Presentation.

We will design an apartment complex in Watts, CA for low-income families and retirees. We want our building to be innovative, resilient, high quality, net-zero, energy efficient, and locally responsive. To cater our building towards the needs of the Watts community, we want our building to connect residents and community members to nature, qualify as low-income housing to make it affordable, provide a haven for residents and local children, and follow PHIUS passive housing standards to cut down utility costs for the residents and create a comfortable living environment.

3.1 PROBLEM STATEMENT

Our team is designing a net-zero development in Watts, CA for the Department of Energy's Solar Decathlon competition. Our building must be designed to follow the competition guidelines, and create a positive, meaningful impact on the community it is designed for. Due to gentrification in Los Angeles leading to higher living costs and emerging threats of climate change, low-income individuals and families in Watts need affordable, sustainable, and net-zero energy housing that will last for generations to come. By providing this demographic with affordable housing, it becomes possible to build a stable community while address pressing environmental needs.



Figure 5. Boundary Diagram

3.3 CUSTOMER NEEDS AND WANTS

Table 2. Customer Needs and Wants

Needs	Wants
Comfortable building environment	Aesthetically pleasing
Net-zero energy usage	Low initial cost
Building size: 300–2,500 ft ² (28–232 m ²) per dwelling unit	Low operating cost
Lot size: up to 3,000 ft ² (279 m ²) per dwelling unit	Low maintenance cost
Meets or exceeds the DOE Zero Energy Ready Home National Program Requirements (Rev. 07)	Short construction period
Meets or exceeds the requirements set out in the California residential net-zero	Improved air quality
Durable structure	
Affordable	
Constructed using sustainable materials	
A safe community space	

3.4 QUALITY FUNCTION DEPLOYMENT

A Quality Function Deployment (QFD) was generated to completely define all aspects of the problem we will be solving with our design, how we intend to test those aspects, and comparison to existing products. First, a list of customer needs and wants were generated based on research from the competition website as well as information about the region for which we are intending to develop this structure. Engineering specifications were then developed to test these needs and wants. These specifications were based on metrics by which residential structures are typically evaluated. The relationships between these specifications and customer needs and wants were then identified, as well as target values for the specifications. These target values were based on EPA guidelines, ASHRAE standards, competition requirements, and other organization guidelines. Existing products were evaluated on the same specifications. Unfortunately, some of these measurements were not readily available about the existing structures we were analyzing, so we had to make estimates. This process is summarized in the House of Quality found in Appendix A: House of Quality.

3.5 ENGINEERING SPECIFICATIONS

Table 3. Engineering Specifications

Spec #	Specification Description	Requirement or Target (Units)	Tolerance	Risk	Compliance
1	Energy Use Intensity (EUI)	15 kBtu/sqft/year	Min.	M	A, S
2	Energy Generation	4000 kWh/yr/person	± 200 kWh/yr	H	A, S
3	Insulation Efficiency	R-20	Min.	L	S
4	Cost Analysis for Project	\$500,000\$4.5 million	Max.	H	A
5	Indoor Air Quality	0.35 Air Changes/hr	Min.	L	A, S
6	Home Energy Rating System	0	Max.	H	T, A
7	Environmental Impact Analysis	Follow EPA CPG	Min.	H	A
8	Lighting Power Density	1.2 W/sqft	Max.	L	A, S
9	Structural Analysis	Meets CA Building Codes	Min.	M	T, A
10	Appearance Survey	75% Satisfaction	Min.	M	T, I
11	Cost of Mechanical Systems	\$100,000	Max.	H	A, S
12	Size	30,00016,000 sqft	<u>Max.</u>	L	A
13	Indoor Humidity	50%	$\pm 10\%$	L	A, S
14	Cost of Water Usage	\$63.22/month	Max.	L	A
15	Savings over average home	\$10 per sqft	Min.	M	A, S
16	Time to Construct	3 months	Max.	M	A, S

Each of these engineering specifications must have a method to quantify them. For the Analysis, Testing and Similarity to Existing Designs, average values from the geographical location will be used to measure the specifications. For example, the energy use intensity (EUI) will be measured by dividing the average energy consumed by the home in one year over the gross floor area of the home. For the Inspection category, the appearance survey will be done by clients reviewing the photos we submit for the competition. Since the competition is design-only, it is not in our scope to build a full prototype. Thus, the majority of our testing will be done with average values given by public sources of data, such as census data or geographical location data.

The high-risk specifications for this project are energy generation, cost analysis, Home Energy Rating System score, and environmental impact analysis. These represent the major competing aspects of the structure that we must balance throughout the design process. The energy generation will be difficult to achieve at a low cost because we will need to generate as much energy as the structure will consume. Maintaining the affordability of the structure will pose a challenge as many renewable and sustainable technology tend to be more expensive. Balancing these three specifications is the major challenge we will face in our design.

4. CONCEPT DESIGN

Below are subsections of how we developed our concept design. Through multiple ideation sessions and creating the Pugh and morphological matrices, we concluded with a design concept that will serve as a framework for our future design iterations.

4.1 DESIGN IDEATION

We started our design ideation process by brainstorming individually. We used brain dumping to procure ideas about individual components of the house such as power systems, HVAC, building envelope, and lighting. The results of these brain dumping sessions can be seen in Appendix I: Brain Dump and Appendix J: Jamboard group brain dump session. We then performed group ideation sessions where we used Google Jamboard to perform brain writing, using 1 slide per person. In this brain writing session, we built on others' ideas in 1-minute intervals before switching to the next person's ideation slide. Each of the resulting slides can be seen in Appendix K: Jamboard Brain Writing.

After our initial ideation processes, we created a Functional Decomposition Tree based on the functions of the net zero house. This identified the main functions that the design will perform and then broke those main functions into sub-functions, which allowed us to pursue more targeted design choices. We found the five main functions of the house as follows: promote safety, maximize occupant comfort, provide customer satisfaction, promote sociability, and promote sustainable practices. The functional decomposition tree can be seen below in Figure 6. We then chose several of the most important functions from the Functional Decomposition Tree to construct Pugh Matrices for. These Pugh matrices explored and compared various options that would fulfill those individual functions. We created Pugh matrices for the power systems, HVAC systems, building envelope, and structural components/windows. All Pugh matrices can be seen in Appendices C, D, E, and F. From the top 2 ideas ranked in each of the Pugh matrices, we generated 8 design concepts using a morphological matrix. This morphological matrix, seen in Figure 7 below, defined possible solutions to each function with sketches. The 8 design concepts were put into a weighted decision matrix, from which we chose the top overall concept design. See Appendix L: Weighted Decision Matrix and Appendix M: Weighted Decision Matrix Concept Design Sketches for the weighted decision matrix and concept sketches.

During the ideation process we also generated several low-resolution concept prototypes. These prototypes were quickly generated out of low-cost materials to allow for frequent iteration. This allowed us to observe some preliminary feasibility of our ideas as well as explain our ideas to the team using a visual aid. These concept prototypes can be found in Appendix N: Function Prototypes

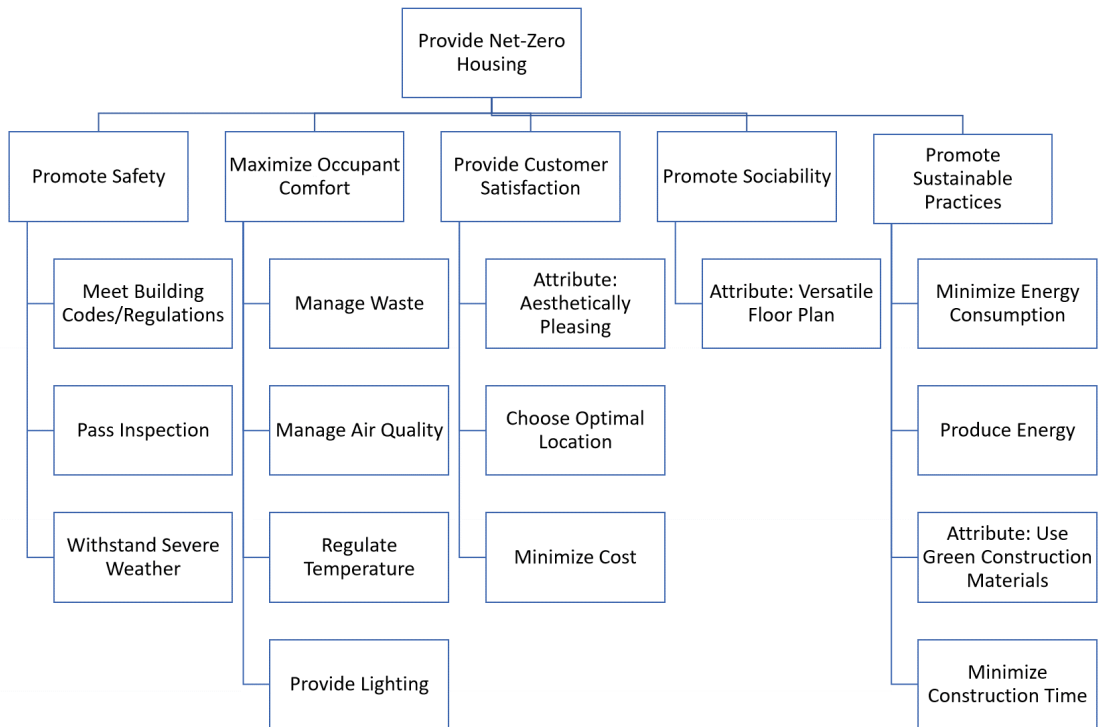


Figure 6. Functional Decomposition Tree


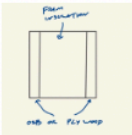
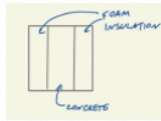


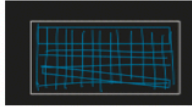
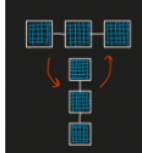



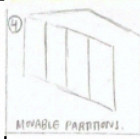




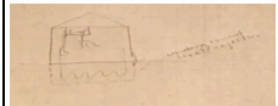
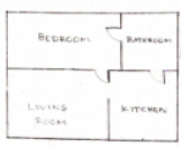
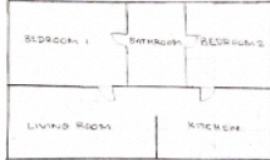
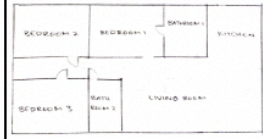
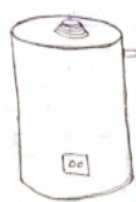

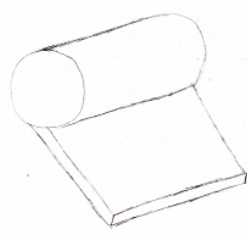
Functions	Idea 1	Idea 2	Idea 3	Idea 4
Building Envelope	Traditional Framing 	Structurally Insulated Panels (SIP) 	Insulated Concrete Forms (ICF) 	Storage Container 
	Multilevel SP 	Large sheet SP 	Reconfigurable SP 	Kinetic Energy (bike) 
Natural Lighting	Angled roofs 	Adjustable shading 	Movable partitions 	Triple pane windows 
	Minisplit 	Split System 	PTAC 	Geothermal 
Floor plan	1 bedroom 	2 bedroom 	3 bedroom 	
	tank heater 	tankless heater 	solar water heater 	

Figure 7. Morphological Matrix

4.2 TOP CONCEPTS

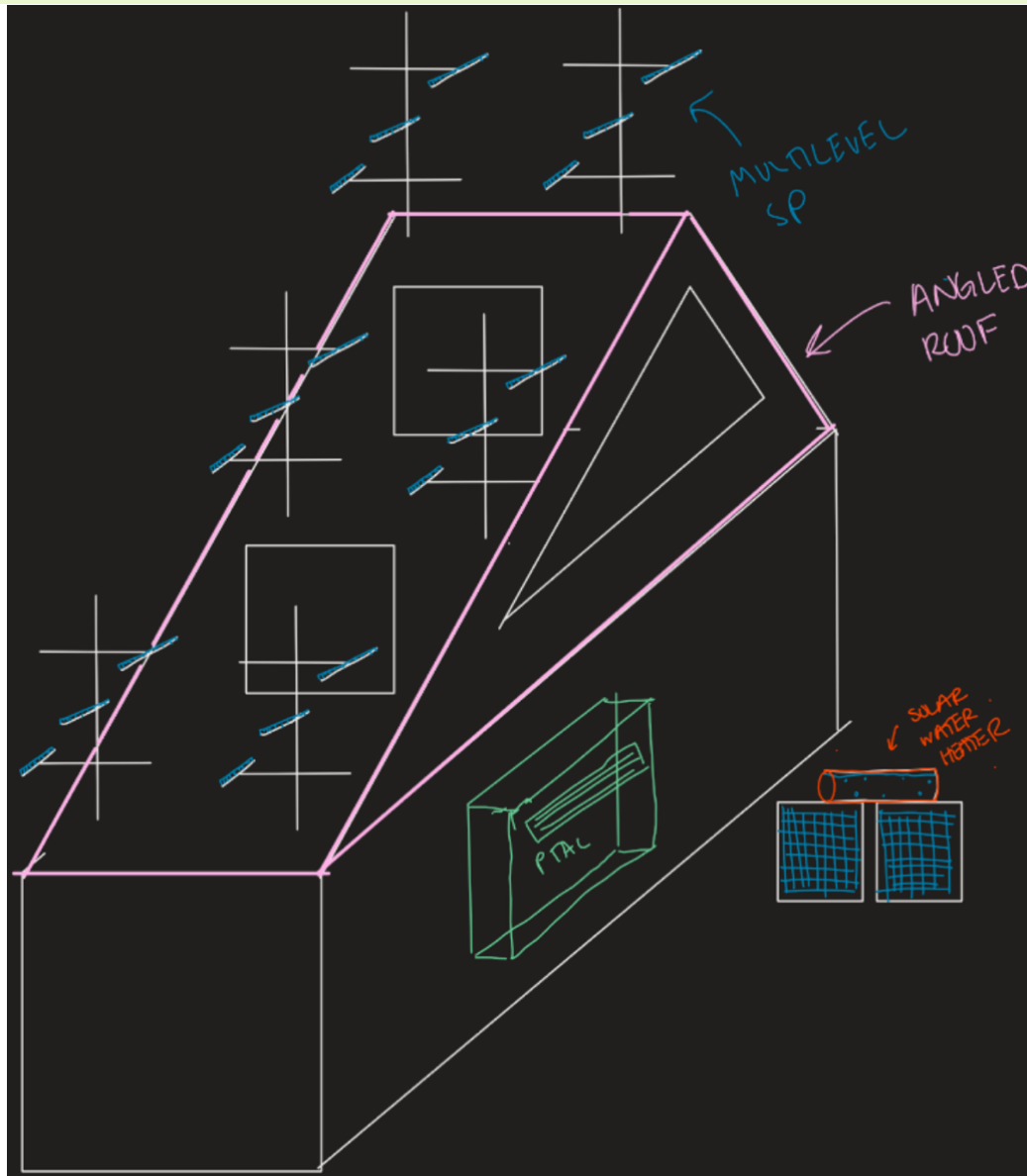


Figure 8. Design Idea 1

Design Idea 1 consists of a 1-bedroom home constructed out of shipping containers to reduce the environmental impact of our construction and make construction time faster. The roofs are angled to let ambient light in, reducing overall energy consumption. On the roof are a series of multilevel solar panels to maximize energy production.

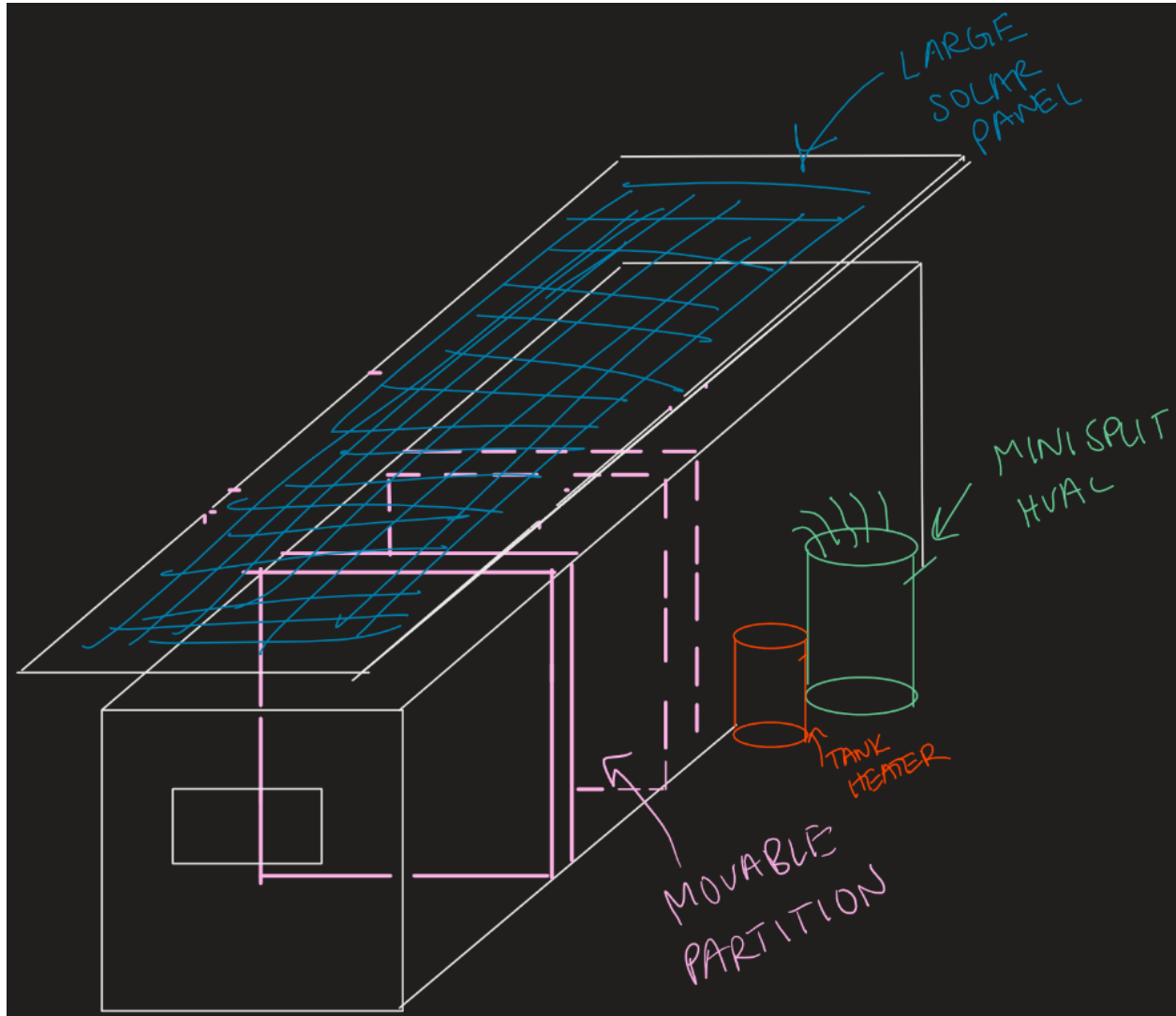


Figure 9. Design Idea 2

Design Idea 2 is a 2-bedroom home with movable partitions to allow homeowners to rearrange the house to better suit themselves as they get accustomed to the space. There is a mini-split HVAC to reduce operating HVAC costs and reduce energy consumption. The house has a standard tank heater powered by the large solar panel that extends the length of the roof.

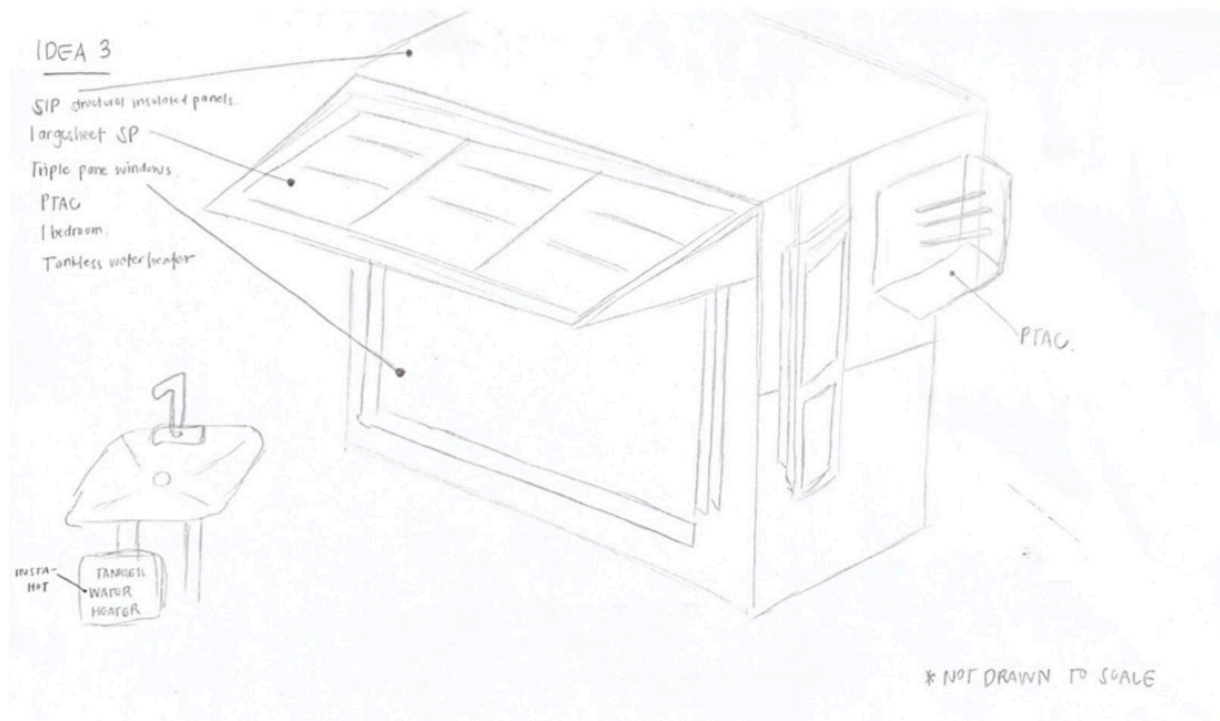


Figure 10. Design Idea 3

This home is designed with structural insulated panels for easier construction. The awning has a large solar panel attached to it and the home will be oriented in a way so that the panel captures the most sunlight. All the windows in the home are triple glazed to optimize heat transfer in the space. This home uses a tankless water heater because the load is small for the one-bedroom home. The HVAC system chosen is a PTAC, a small unit mounted to the side of the home.

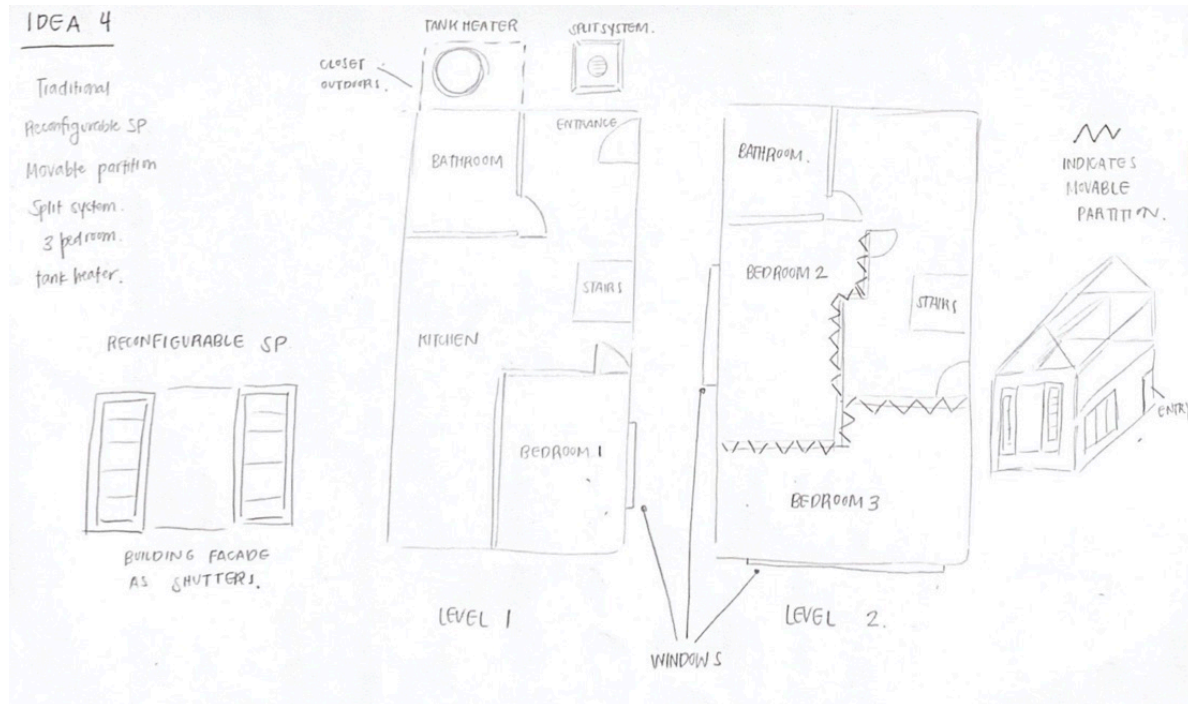


Figure 11. Design Idea 4

This idea uses the traditional structure and it has reconfigurable solar panels. The solar panels mimic window shutters, so the occupant will adjust according to the time of day. There are movable partitions within this home to open the home on the second floor. There are three bedrooms in this two-story home and it is a relatively thinner housing layout to fit in interstitial areas, optimizing lot sizes. There is a tank heater to supply domestic hot water in the home and it uses a split system to provide cooled and heated air throughout the house.

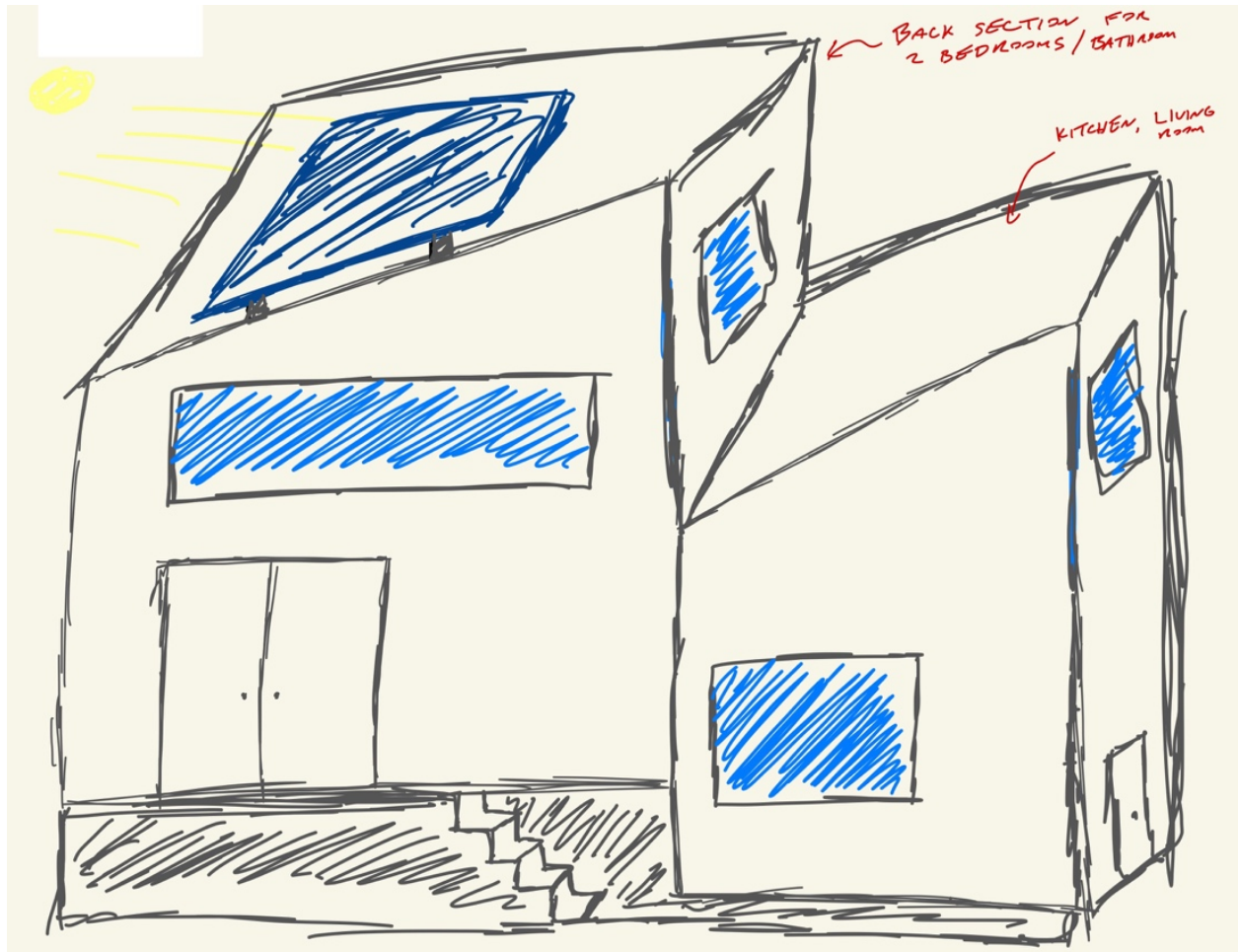


Figure 12. Design Idea 5

This idea features a two-bedroom house with an insulated concrete form building envelope, large sheet solar panels, angled roofs, a mini split HVAC system and tankless water heaters. The ICF building envelope will provide great thermal insulation during both hot days and cold night, while the angles roofs aim to maximize roof space for solar panels while maintaining enough natural light.

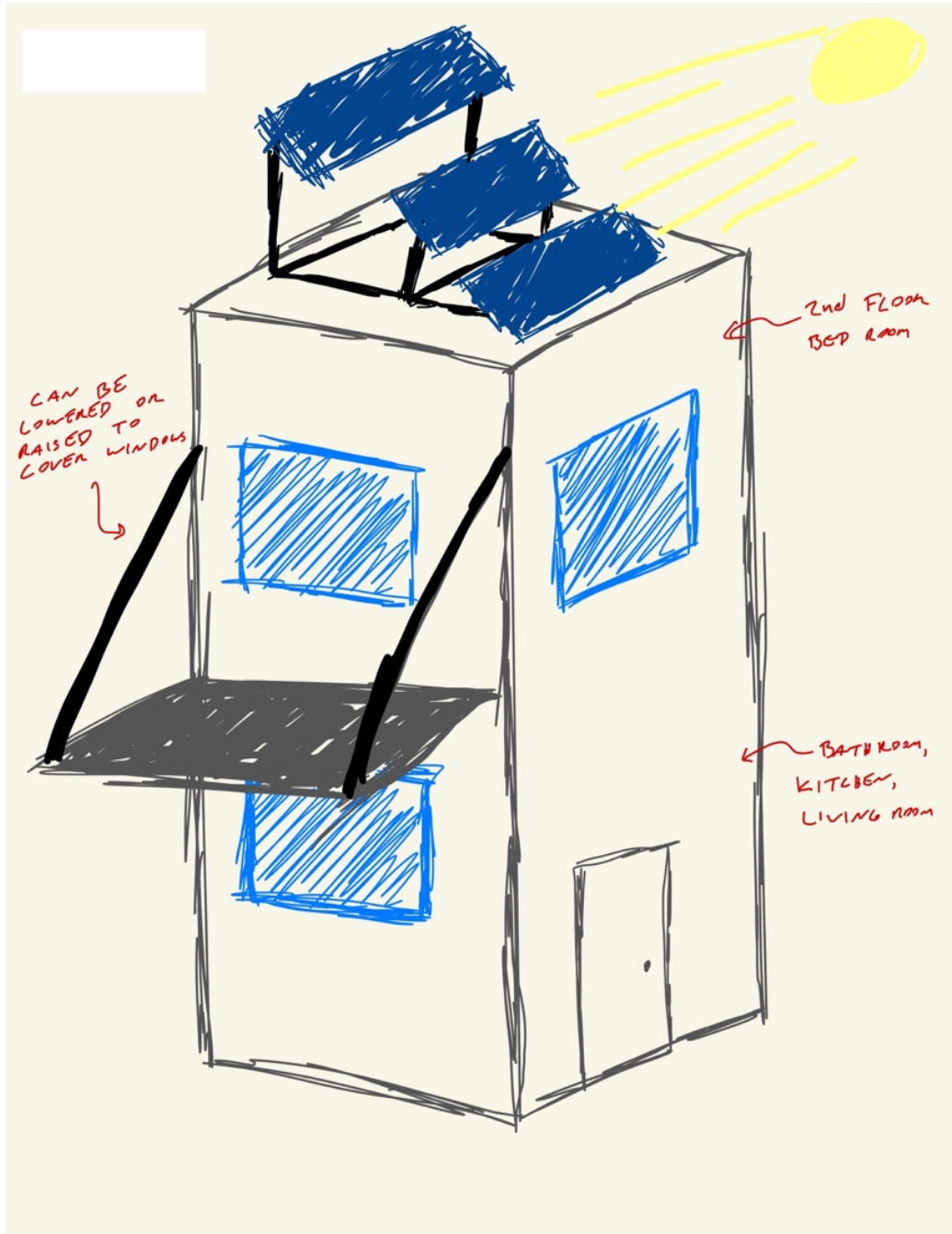


Figure 13. Design Idea 6

This is a single-bedroom home maximizes the small lot size by having multiple stories. The multi-level solar panel array is designed to maximize the amount of energy production on such a small rooftop. The adjustable shading can be lowered or raised to cover windows to provide privacy and an extra layer of thermal protection on extreme weather days. The building envelope utilizes structurally insulated panels to ensure a quick onsite construction time and sufficient thermal insulation.

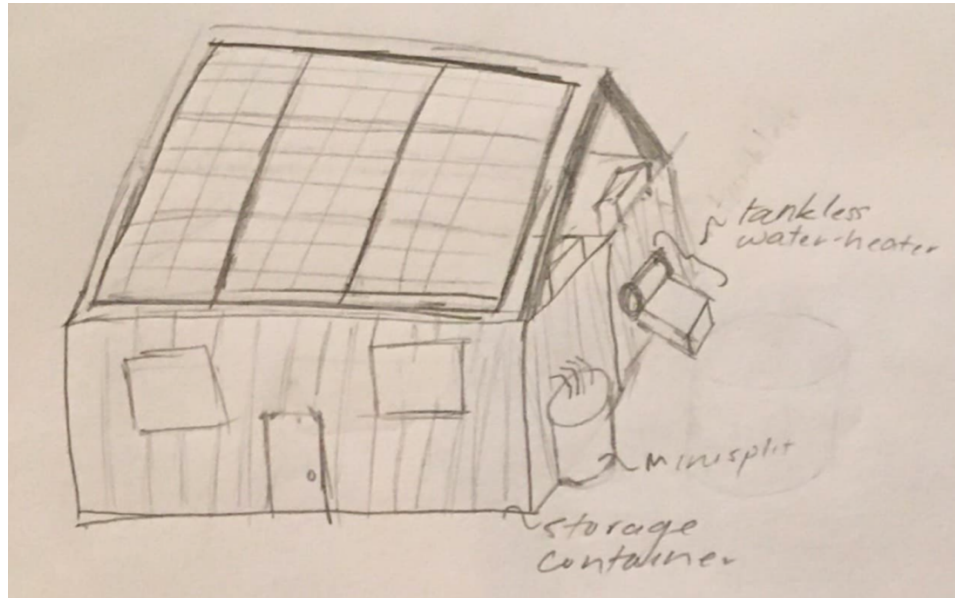


Figure 14. Design Idea 7

Design Idea 7 is a two-bedroom house constructed out of storage containers. There is a sheet solar panel on the roof, which is adjustable to maximize solar power. It has a mini-split HVAC system and a solar water heater.

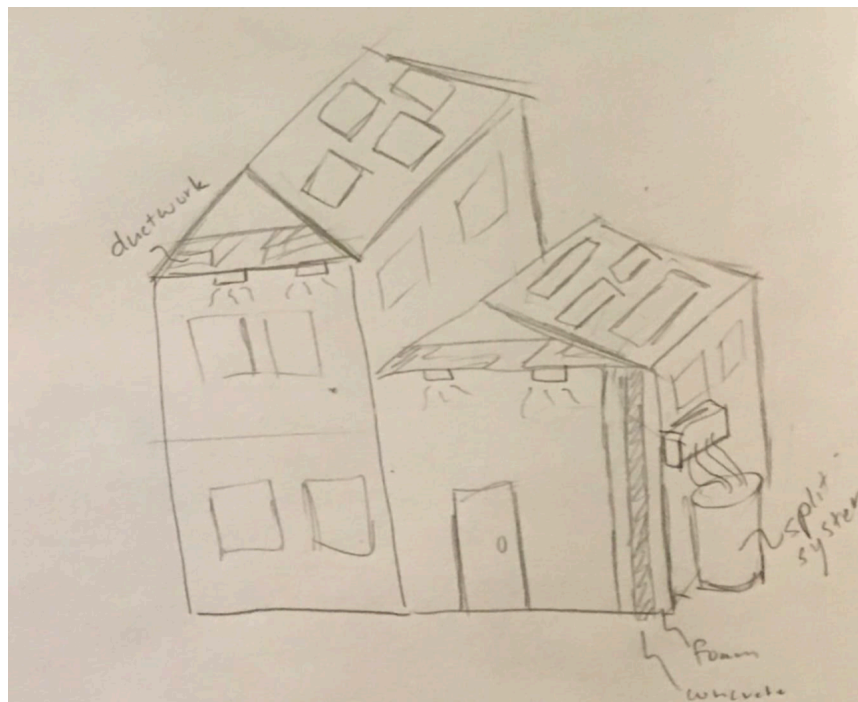


Figure 15. Design Idea 8

Design Idea 8 is a three-bedroom house constructed using ICF as the envelope. Energy is provided via reconfigurable solar panels. Comfort is provided by adjustable shading of the windows, a split system HVAC, and a tankless water heater.

Specifications	Weight	1		2		3		4	
		Score	Total	Score	Total	Score	Total	Score	Total
Net-zero energy usage	5	4	20	4	20	5	25	4	20
Building size: 300–2,500 ft ² (28–232 m ²)	5	5	25	5	25	5	25	2	10
Lot size: up to 5,000 ft ² (465 m ²)	5	5	25	5	25	5	25	2	10
Meets or exceeds the DOE Zero Energy Ready Home National Program Requirements (Rev. 07)	5	5	25	5	25	4	20	4	20
Meets or exceeds the requirements set out in the California residential net-zero	5	4	20	4	20	4	20	4	20
Durable structure	4	2	8	2	8	4	16	3	12
Affordable	4	4	16	4	16	3	12	4	16
Constructed using sustainable materials	3	3	9	3	9	3	9	2	6
Aesthetically pleasing	4	3	12	3	12	4	16	3	12
Low initial cost	4	3	12	4	16	3	12	4	16
Low operating cost	2	4	8	4	8	3	6	4	8
Low maintenance cost	3	3	9	3	9	5	15	4	12
Short construction period	1	5	5	5	5	3	3	2	2
Comfortable building environment	4	4	16	4	16	4	16	3	12
SUM TOTAL:			210		214		220		176

Specifications	Weight	5		6		7		8	
		Score	Total	Score	Total	Score	Total	Score	Total
Net-zero energy usage	5	5	25	5	25	3	15	5	25
Building size: 300–2,500 ft ² (28–232 m ²)	5	4	20	5	25	5	25	3	15
Lot size: up to 5,000 ft ² (465 m ²)	5	4	20	4	20	4	20	3	15
Meets or exceeds the DOE Zero Energy Ready Home National Program Requirements (Rev. 07)	5	5	25	4	20	4	20	4	20
Meets or exceeds the requirements set out in the California residential net-zero	5	5	25	3	15	3	15	4	20
Durable structure	4	5	20	3	12	4	16	5	20
Affordable	4	2	8	3	12	4	16	3	12
Constructed using sustainable materials	3	2	6	4	12	4	12	3	9
Aesthetically pleasing	4	4	16	4	16	2	8	4	16
Low initial cost	4	3	12	5	20	4	16	3	12
Low operating cost	2	5	10	3	6	3	6	5	10
Low maintenance cost	3	5	15	4	12	4	12	3	9
Short construction period	1	2	2	1	1	5	5	2	2
Comfortable building environment	4	5	20	3	12	2	8	5	20
SUM TOTAL:			224		208		194		205

Figure 16. Final Weighted Decision Matrix

After rating each design in the weighted decision matrix seen in Figure 16, the highest-ranking concept was Design Idea 5. This idea provides superior durability and thermal comfort by using an ICF building envelope, maximize roof area for solar panels with angled roofs, and minimize energy usage through high efficiency mechanical systems.

4.3 NEW DESIGN DIRECTION

Because of the nature of our project, our design direction is different from the one that we chose through our Pugh matrix and morphological matrix. After discussion with architecture students, we realized that our choice of single-family housing does not meet the needs of the community as well as it could have. The community of Watts is unique because they are dealing with significant social issues as well as housing shortage. Some of the concepts that were discussed in the process are being utilized in our design, but the selected concept below deviates from the one chosen through our analysis.

For the competition, we decided to focus on guiding our design towards working single guardians living in Watts, California, as research has indicated that there is a significant rate of single parenthood in the area. As well as providing affordable housing to single parents in this community, a daycare is also included to provide extra support to the occupants.

The site we have chosen for the structure is located on E 108th St in Watts, as seen in Figure 17 below. It is located near an elementary school, which allows guardians to easily walk their children to school. There is also a bus stop located nearby, which will provide occupants access to public transportation to get to work or for other needs.

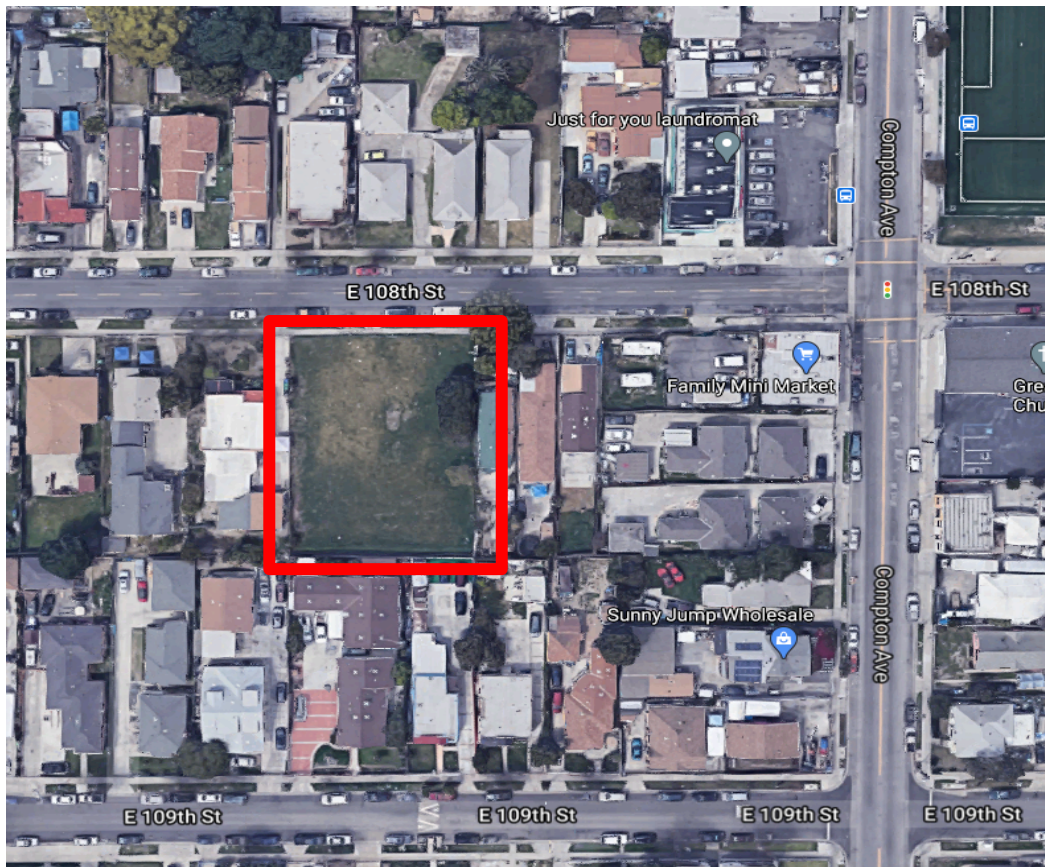


Figure 17. Site location for Structure

Figure 18 shows an isometric view of the first iteration of the building structure from the Rhino file generated by the architecture students on our team. After we received this file and the specifics of the building, we generated a concept prototype and began preliminary engineering calculations for required solar panels (see Appendix O: Solar Panel Calculations). From our preliminary solar panel calculations, we found that we would need about 70 solar panels to cover the electricity needs of 20 residents. These calculations will be refined and furthered once we figure out the final architectural design. We have decided on a variable refrigerant flow HVAC system with an HRV for additional efficiency. This reduces the additional cost and noise of ducts, as well as the space necessary for them. As seen in the figure, there will be a courtyard in the center of the structure for community space or for the children at the daycare. Currently, the daycare is located closest to the street because we are anticipating providing childcare for neighborhood families, rather than just residents and this would allow for easy drop-off.

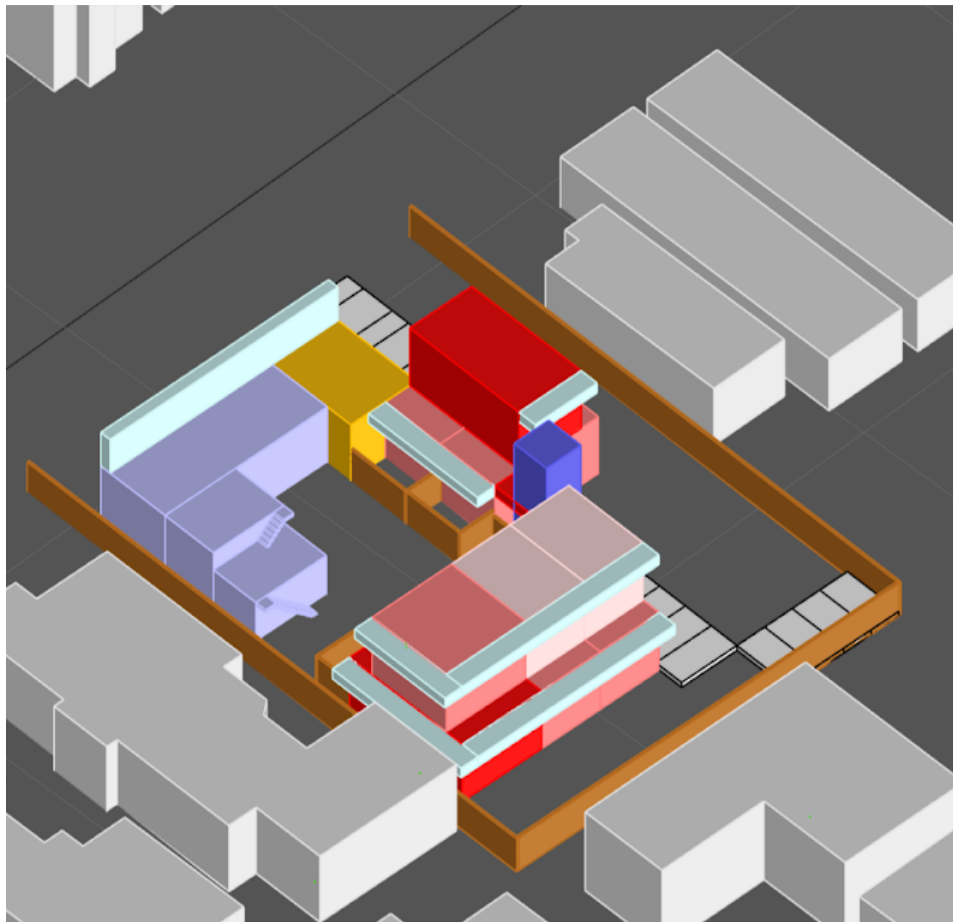


Figure 18. Isometric View of Selected Design

Figure 19 and Figure 20 show the first and second floor plan, respectively. There are nine total units: four two-bedroom units, three one-bedroom units, and two studio units. The daycare and lobby are located on the first floor.

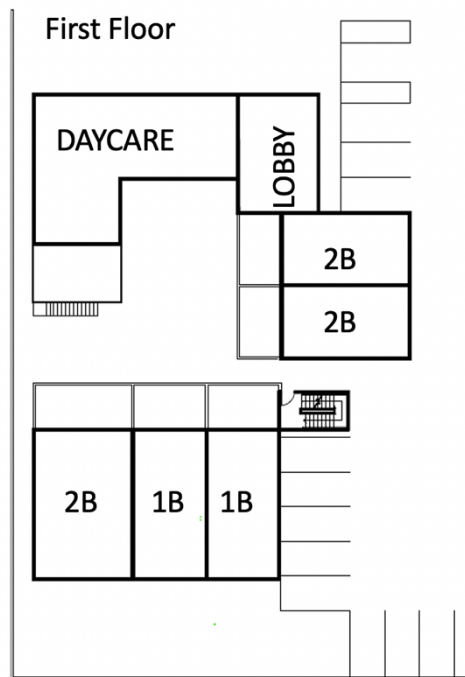


Figure 19. First Floor Plan

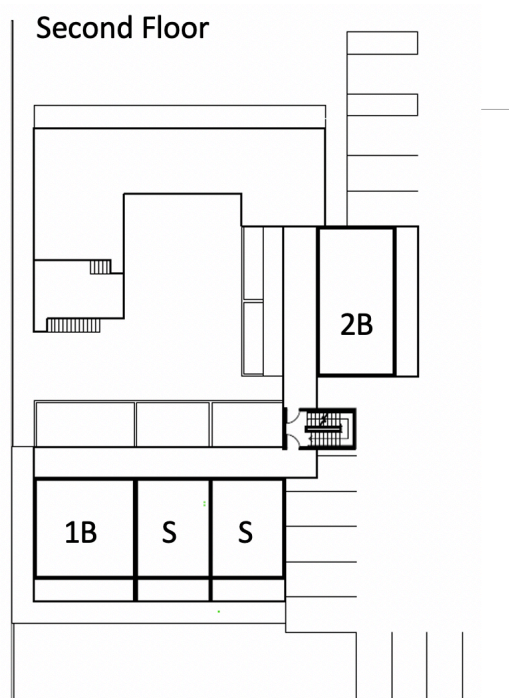


Figure 20. Second Floor Plan

Figure 21 shows the concept prototype that we constructed to represent our selected design. This small architectural model shows the proposed layout of our design. It also demonstrates the amount and distribution of the solar panels that will be used to satisfy the electrical needs of the residents. This prototype showed us that we would have a lot of extra roof space that could be used for community space or a rooftop garden. We also learned that we might experience difficulties in designing an attractive building, because the design is currently not very creative in terms of external aesthetics.



Figure 21. Concept Prototype

In terms of material, we are using the typical wood frame structure with eight-inch-thick exterior walls and six-inch-thick interior walls. To meet the competition's goals of sustainability, we will focus on using recyclable materials throughout the construction. We are also looking to rearrange the floor plan so that the bathrooms are side-by-side and the first-floor bathroom aligns with the second-floor bathrooms. This will allow plumbing risers to be easily installed and reduce any unnecessary pipework in the house.

Since this first concept design was developed, the architecture team has made several more iterations and adjustments on the design. The final design discussion can be found in Section 5.

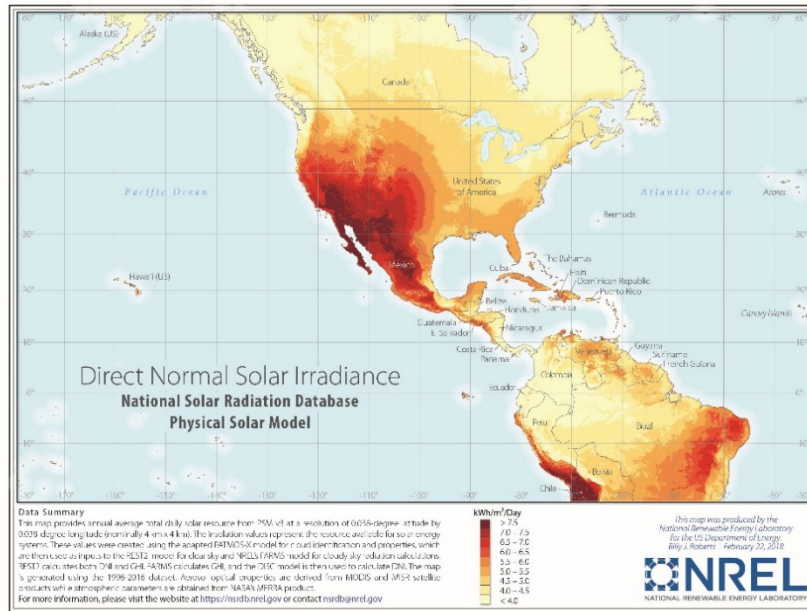


Figure 22. Direct Normal Solar Irradiance Data From the NREL

For our solar panel calculations, we pulled data from Los Angeles county to determine the average electricity consumption per capita. Based on the number of residents in the building, 20, and the electricity consumption per capita, 5.2 kWhr/day, we determined the residential power required for our building. We then found the cheapest solar panel on the market, a ReneSola J255M-24/Bb panel and determined the power output of the panel based on the local solar irradiation levels in the Watts area depicted in Figure 22 above. The power output of the panel accounts for the efficiency of the panel, about 15.7%, as well as the degradation of the panel over its 25-year life, about 80%. From these calculations, we determined that our building would need about 70 solar panels for 20 residents as seen in Appendix O: Solar Panel Calculations. These calculations are rough and do not account for the efficiency loss of the panels due to high temperatures, the additional power required for the daycare, laundry room, and community area, or the variation in electricity use throughout the day. We will be refining these calculations as we develop the building design further.

4.4 DESIGN HAZARDS

Since this is a design challenge only, the design hazards are purely theoretical. In our design hazard checklist, we have identified several social risks, such as having a potentially sensitive population of single guardians with young children (see Appendix P: Design Hazard Checklist). This can be addressed by introducing constant lighting to dark areas of the building like the parking garage. Depending on the severity of safety concerns, we could include a guarded lobby in our design so that access to residential areas is private and protected. During the summer, our building will be subjected to extreme heat. By using passive energy saving methods, like door and window placement, and HVAC systems, we can protect the occupants from the hot weather. Other hazards of the building include structural, seismic, and fire hazards. Seismic and structural hazards can be addressed by performing structural integrity tests on our building model and adjusting the structure accordingly. We can mitigate seismic, structural, and fire hazards by following local building codes and by designing our building to suit the climate. There will be an additional hazard of the refrigerant in the HVAC and refrigerators. The danger posed by this can be mitigated by ensuring that the piping that contains refrigerant has no leaks and is appropriately sized.

5. FINAL DESIGN

5.1 FINAL SELECTED DESIGN OVERVIEW

Our final design is a table-top design with the twelve residential units elevated above the communal areas of the attached housing structure. Detailed drawings of the structure in addition to manufacturers' cut sheets for mechanical equipment can be found in the Drawing Package in Appendix U: Drawing Package. The roof of the structure will support the photovoltaic system. The structure is divided into two buildings: one smaller building on the north side of the lot with four units above a parking structure and one larger L-shaped building with eight units above offices, storage space, community space, janitorial closets, and the daycare. The two buildings are connected via a concrete platform and form a courtyard. An architectural 3D rendering can be found in Figure 23, where the green represents green space and yellow represents the PV arrays. Figure 24, Figure 25, and Figure 26 contain the comprehensive floor plans. These 3D renders and floor plans were generated by the architectural side of our team. Figure 24, Figure 25, and Figure 26 contain the comprehensive floor plans.

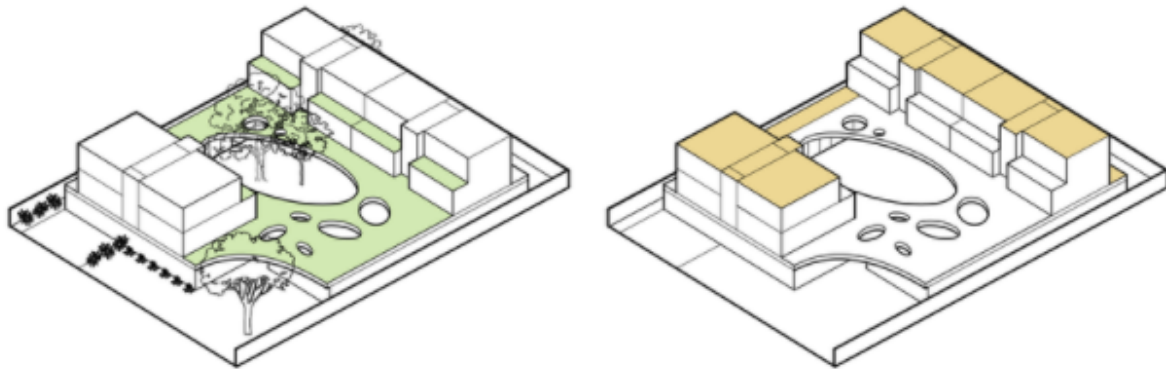


Figure 23. 3D Rendering of Attached Housing

Figure 24 shows the floorplans of the first floor. This includes all communal areas of our structure, such as the community space/daycare, parking, offices, lobby, maintenance rooms, and storage. The parking, community space, and storage spaces will not be conditioned. This means that the floors of the units above these spaces must be insulated more than floors that are between conditioned spaces.

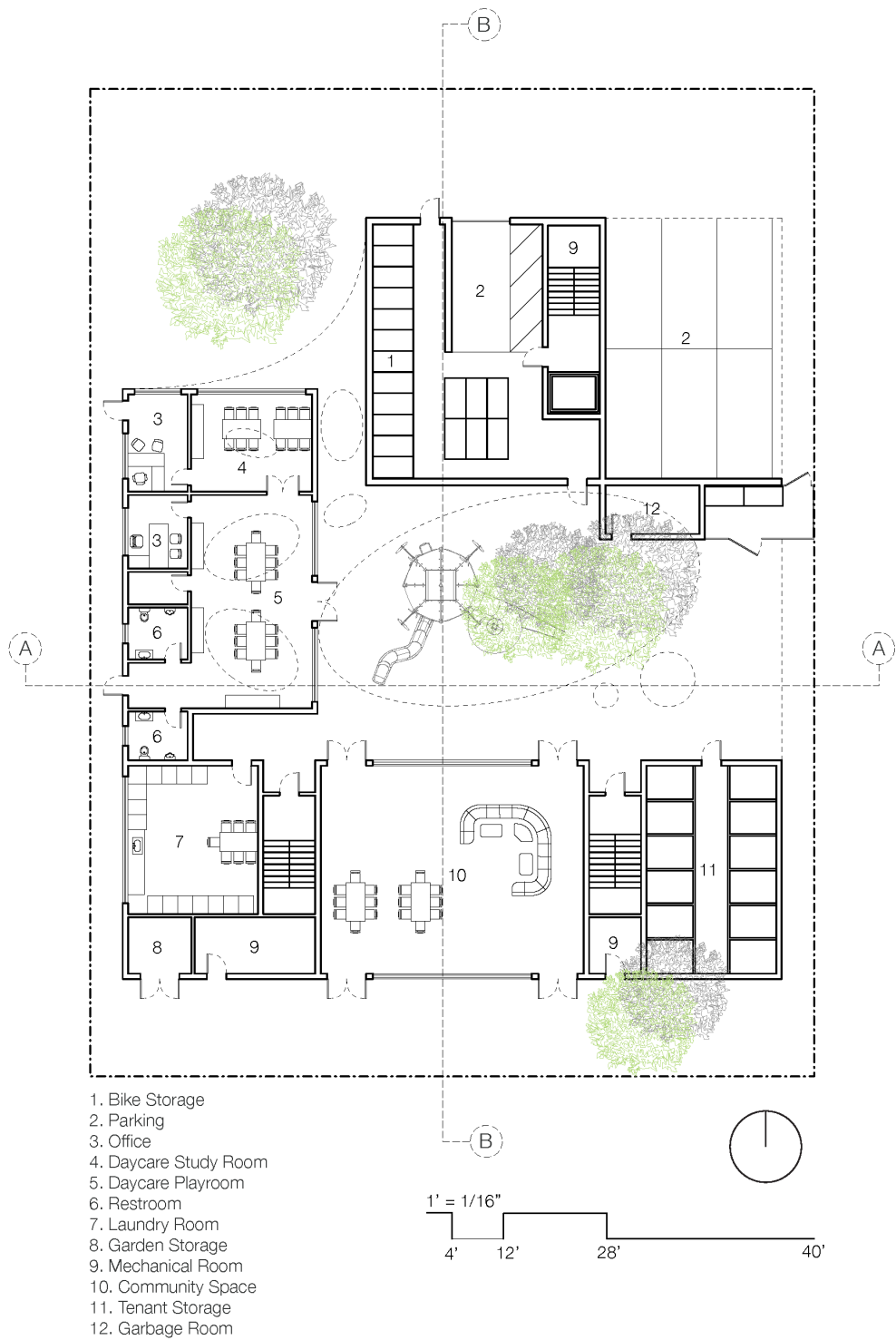


Figure 24. First Floor Layout.

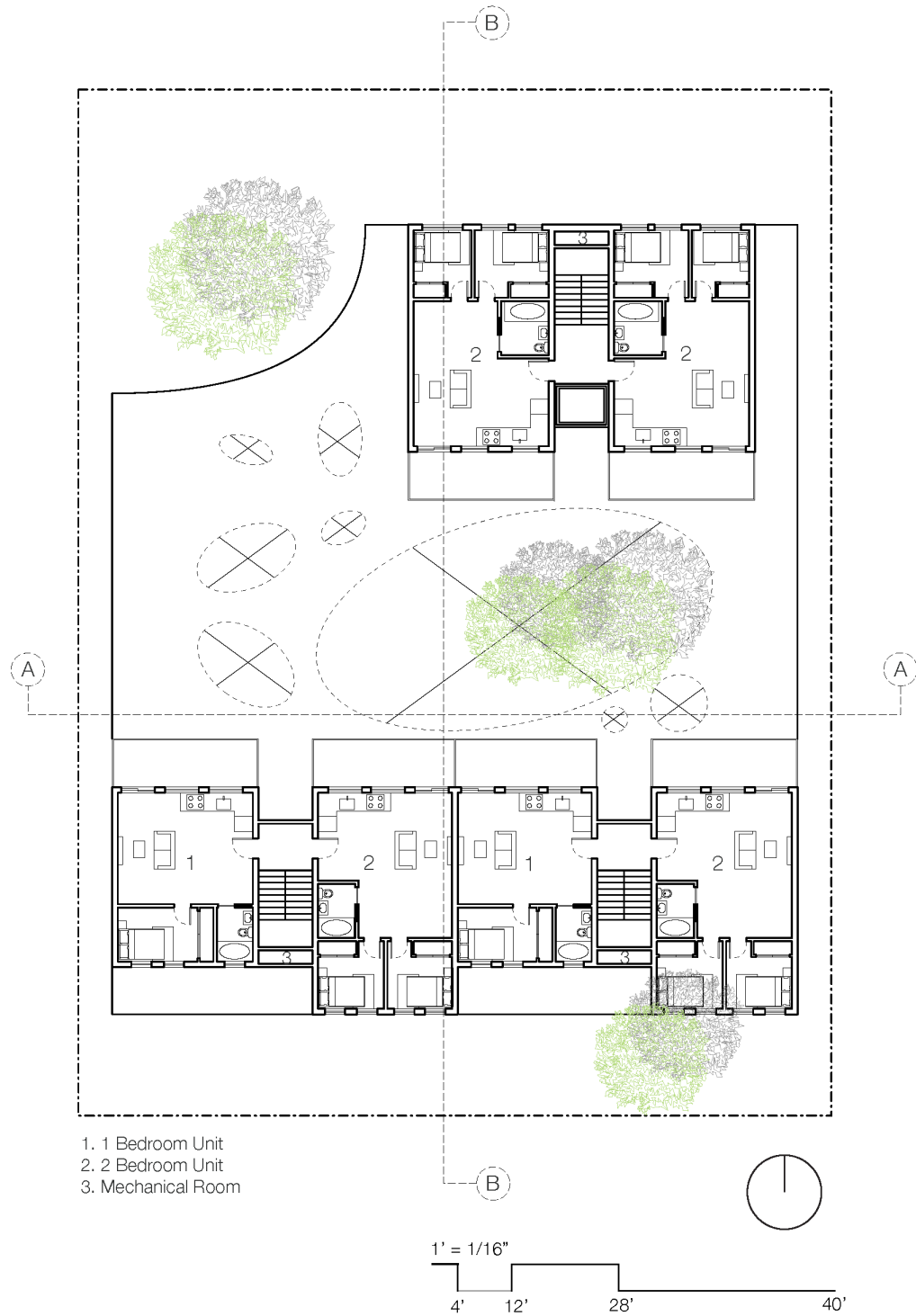


Figure 25. Second Floor Layout.

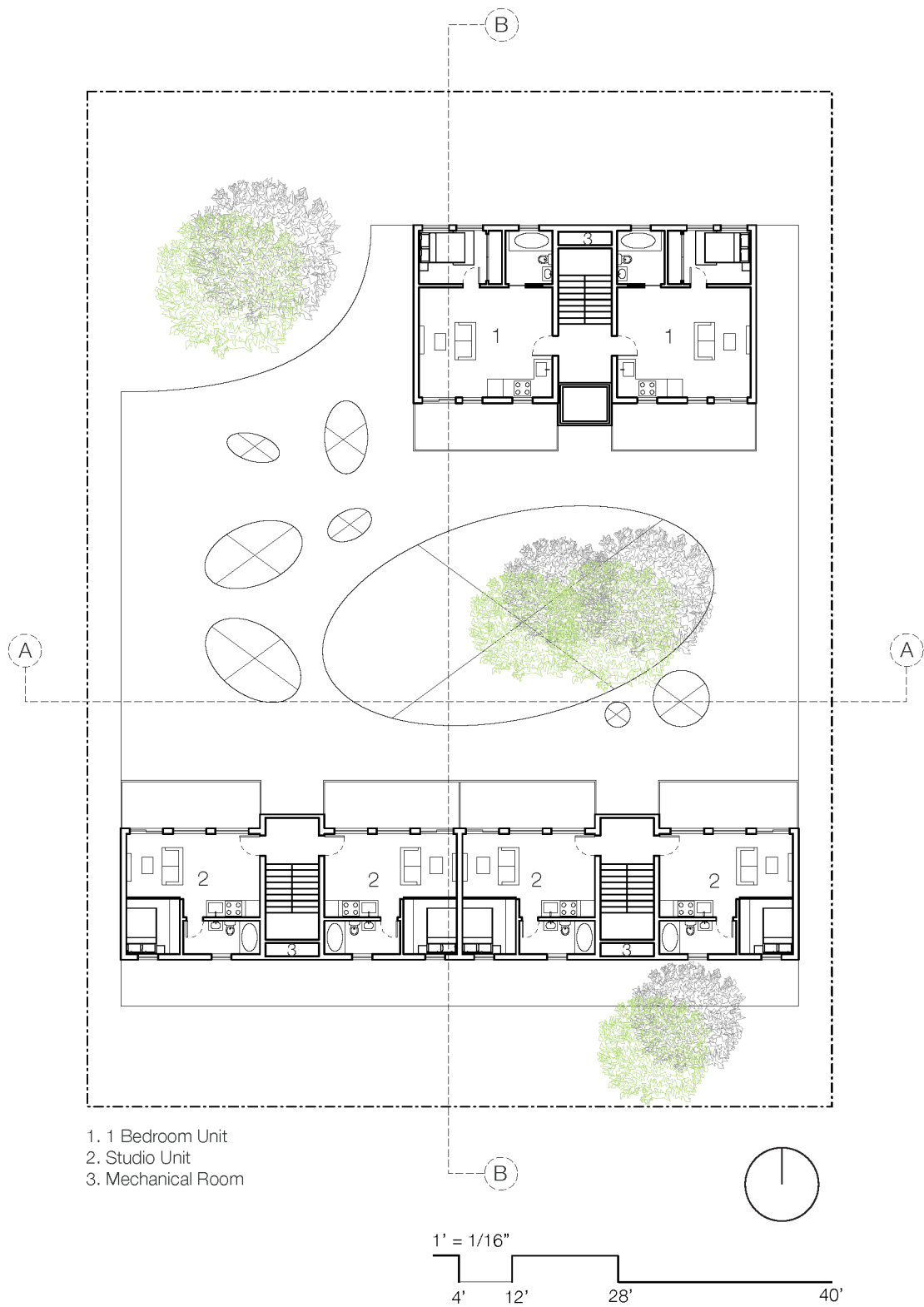


Figure 26. Third Floor Layout.

5.2 FUNCTIONALITY

In developing and creating our design, our project meets four main goals: passive house and net-zero design, climate considerate, community-based service, and affordability. The well-insulated building envelope will mitigate the need to use the traditional HVAC, Variable Air Volume (VAV) system, which is a major source of energy consumption in a building. The HVAC system itself is designed with respect to energy efficiency, as shown by the selection of a Variable Refrigerant Flow (VRF) system and heat-recovery ventilation (HRV). Landscaping and construction materials are guided by climate considerations. We also aim to include community-based services to integrate the housing complex into the existing community and offer resources to our residents.

5.2.1 ARCHITECTURE DESIGN

The twelve residential units include four one-bedrooms, four two-bedrooms, and four studios. The lower level includes a community space that will also serve as a daycare and community space to provide families with childcare during the workday. Four of our units (two one-bedrooms and two two-bedrooms) are ADA compliant, meeting the dimensional and accessibility requirements for families with disabilities. Our building will utilize a green roof to further insulate the roof of the building, contribute to the natural aesthetics of the building, and create a cooler microclimate around the building to combat the urban heat island effect.

5.2.2 MECHANICAL DESIGN

The air-temperature control of our units will be supplied by an air-cooled VRF system. The outdoor condensing units for the refrigerant will be located on concrete pads on the ground level near the building. The ventilation for the building is provided by a Dedicated Outdoor Air System (DOAS). The main DOAS unit will ventilate each room with supply air from the roof of the building. Included in the DOAS unit will be a Heat Recovery Ventilator (HRV) to pre-heat incoming air with the stale exhaust air. The HRV is a heat exchanger that is used to reduce the loads for heating and cooling.

5.2.3 PLUMBING DESIGN

The plumbing will be compliant to all California Plumbing code where vent, sanitary sewer, domestic water, and greywater systems will match all sizing requirements. To lower our water consumption, all water fixtures will be selected from the EPA's WaterSense list. These fixtures (toilets, faucets, showerheads) have lower than average flow rates which lowers the building's water usage. Because Los Angeles County requires new construction to be greywater ready, we will implement a system in our design to use the water for landscaping and irrigation around the building. Depending on the amount of water our laundry machines produce, we will most likely implement a laundry to landscape system which takes water directly from the laundry machines and uses it to irrigate plants on-site. We are considering several water heating methods: tankless, heat pump, and solar thermal. We will most likely use a heat pump as it is highly efficient, however more analysis is required to finalize the selection.

5.2.4 ELECTRICAL DESIGN

Electrical design includes design of the PV system as well as selection of appliances and lighting fixtures. All appliances are selected from the Energy Star certification program to reduce plug loads. These choices are made to minimize the on-site energy consumption and to reach our net-zero goal. To match our energy consumption, a solar PV system is installed on the roof of each building and on shade structures to produce energy throughout the day. Due to California's net-metering policy, the PV system is grid tied with a backup energy storage system, putting excess power into the battery and grid when overproducing and drawing power from the battery and grid when underproducing.

5.2.5 BUILDING ENVELOPE

We are constructing a highly insulated wood-framed and concrete structure with our design decisions regarding the envelope. Our attached housing follows a passive house model where insulation, window, and door selections are made with respect to the PHIUS recommendations for our climate zone. This limits the amount of heat gain in the summer and heat loss in the winter, therefore reducing the amount of energy needed for cooling and heating with our mechanical systems.

For the public first floor of the building, we will utilize a concrete podium massing to support the residential floors and provide more area for green spaces and mechanical units. For the residential floors of our building, we are utilizing a traditional wood framed structure with 2 x 6 studs spaced 16 inches on center. Cellulose and EPS rigid foam board insulation fill the wall, floor, and ceiling cavities to meet Title 24 and PHIUS specifications. A preliminary exterior wall insulation design is shown in Figure 27 with the layer of materials displayed left to right as follows: 1" external stucco, .625" plywood, 2" rigid insulation board, 5.5" cellulose fiber, 5.5" wooden studs, and .625" plaster board. We finalized this design in the manufacturing portion of the project.

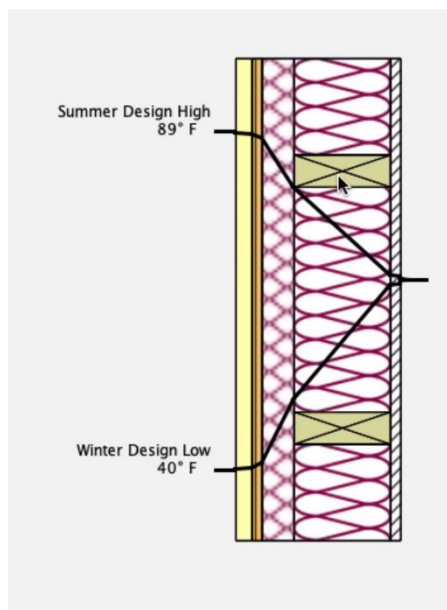


Figure 27. Preliminary Wall Insulation Design from Opaque

5.3 MATERIAL AND PART SELECTION JUSTIFICATION

5.3.1 MECHANICAL JUSTIFICATION

The VRF system is ideal for our net-zero attaching housing because it allows thermostats to be directly controlled by occupants in each thermal zone. Because this system transfers heat through fluid in pipes, compared to traditional air ducts, it performs more efficiently. It also reduces the amount of ceiling space that is needed within the building, as refrigerant piping to fan coil units are much smaller than ductwork.

The DOAS unit with HRV is selected based on the climate of our location. Since Los Angeles County experiences low rates of humidity, an HRV will be more properly suited than an energy recover ventilator. The central DOAS unit allows for higher efficiencies than individual units, further reducing energy consumption, while providing clean, fresh air.

5.3.2 PLUMBING JUSTIFICATION

As stated previously, several water heating systems are being considered: tankless water heaters, heat pumps, and solar thermal. Heat pumps are the primary candidate for water heating as they are 2-3 times as efficient compared to traditional electrical resistance heating. Tankless water heating is about 24-30% more efficient than standard storage tank water heaters and have lower operating and energy costs. Solar thermal is 70-80% efficient and space saving compared to solar PV panels necessary for producing electricity for water heating. There has been concern with solar thermal taking away roof space necessary for PV panels. Since solar thermal does not need direct sunlight, we can use them on areas of the building that are subjected to shade (east, west, north walls, shading devices, etc.) to ensure adequate roof space for our panels. Due to solar thermal systems being expensive compared to conventional PV, it is less likely that we can utilize solar thermal in our design. However, we are considering a combination of solar thermal and heat pumps, using solar thermal collectors to preheat water for the heat pump. Analysis via excel will be conducted within the next week to compare the cost, size, and efficiency of each of these systems.

High efficiency, low-flow water fixtures are selected from the EPA's WaterSense list to minimize water consumption. Additionally, a graywater system will be implemented to recycle graywater from laundry washing machines to irrigate the building's landscaping.

5.3.3 ELECTRICAL JUSTIFICATION

The PV system will be grid-tied, meaning that the grid will act like a battery for our building. When excess electricity is produced on-site, it will be transferred to the grid, and the opposite will be true when the PV system is under-producing (during night or cloudy days for example). This ensures that energy availability will not be dependent on weather. Furthermore, the effects of regular power outages that Southern California has experienced in recent years will be lessened for our residents with the backup energy storage system. The backup energy storage system also allows the building to be energy independent during utility power outages, making our power system more durable than standard grid-dependent power systems.

5.3.4 BUILDING ENVELOPE JUSTIFICATION

Concrete construction is utilized for the 1st floor due to its thermal massing capability, absorbing heat in the day that gets released at night, reducing the heating load and cost. Traditional wood-frame construction is utilized for the 2nd and 3rd floors due to its low carbon impact and earthquake resistant qualities when compared to other construction methods like steel-frame or concrete. The cavity created by the 2” x 6” studs spaced 16” apart provides the additional space required for the internal insulation to meet PHIUS and Title 24 R-value requirements. To create a continuous thermal boundary and decrease the risk of thermal bridging, rigid board insulation will be utilized on the outside of the wooden studs. Building envelope design decisions were made with respect to both Title 24 California Energy Code and PHIUS guidelines as seen in Table 1. The former ensures we meet code requirements for inspection, while the latter steers our design towards a highly energy efficient structure.

Table 4. Minimum Building Envelope Insulation R-values.

Minimum R-Values			
Standards	Wall	Floors	Ceiling
PHIUS	27	15	56
Title 24	20	19	22

Since the competition requires the evaluation of the building’s life cycle, a material’s embodied carbon impact influenced the final selection more than any other metric with cost as a close second. Figure 28 compares the carbon impacts of various insulation materials. Dense pack cellulose has one of the lowest embodied carbon impacts compared to other affordable insulation materials like wool, denim, fiberglass, and mineral wool. Although innovative solutions like hemp-wool and straw bales have a larger negative embodied carbon impact than cellulose, they were ultimately ruled out due to cost and construction compatibility. Compared to all other insulation materials, cellulose is the least expensive in terms of price per square foot.

Material options for rigid board insulation include extruded polystyrene (XPS), expanded polystyrene (EPS), polyisocyanurate, polyurethane, and rigid cork panels. We decided to avoid XPS and polyurethane altogether due to their high embodied carbon as seen from Figure 28. Rigid cork panels were the most desirable choice due to its negative embodied carbon, but suppliers are limited. Based on availability, embodied carbon, and price, we decided to use EPS as the rigid board insulation for the walls and floors and polyisocyanurate for the roof.

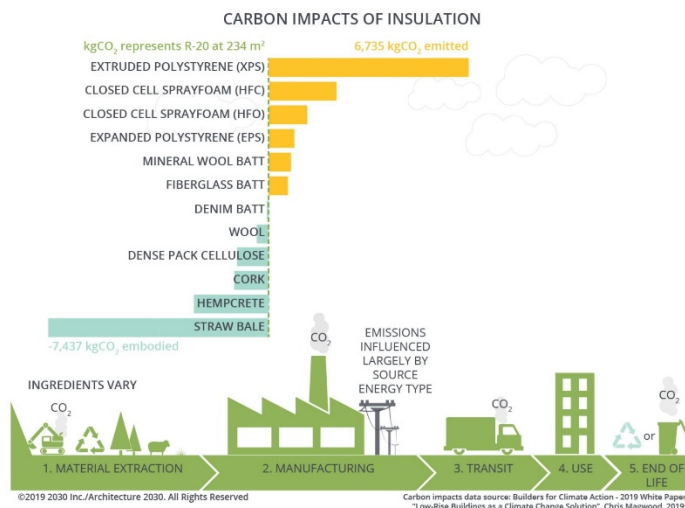


Figure 28. Embodied Carbon Impacts of Insulation Materials

5.4 SAFETY, MAINTENANCE, AND REPAIR CONSIDERATIONS

5.4.1 SAFETY CONSIDERATIONS

Safety of residents is a major concern, given the vulnerable nature of our intended occupants. By elevating the residential units above floor level, we can provide additional safety and privacy. We are also planning to integrate local existing community groups like Safe Passages and Safe Haven into our design that can offer support and create a safe space. Fire safety will be ensured by meeting California Fire Code (Part 9 of Title 24). This includes installation of a sprinkler system, use of construction materials with minimum 1-hour fire rating, and locating all units near accessible means of egress.

The relatively high concentration of air pollution due to traffic, wildfires, and industrial processes also poses a safety concern to residents. We will mitigate this by providing high quality HEPA filters in the ventilation system. The spread of air borne diseases in a dense multi-family residential complex will be mitigated by using a 100% outdoor air system. This means that no air will be recirculated or mixed from multiple units. There will only be supply and exhaust air.

5.4.2 MAINTENANCE AND REPAIR CONSIDERATIONS

Maintenance and repair of mechanical systems will be made possible by locating mechanical equipment in easily accessible locations. Mechanical shafts containing plumbing pipes, refrigerant piping, and ductwork are located against stairwells. Outdoor condensing units for the VRF system are located on a cement pad on ground level. DOAS outdoor air-intake units are located on the roof but will have modes of access for maintenance. Designs of the solar PV system will comply with the California Solar Permitting Guidebook to ensure array accessibility and safety for installers and future maintenance crews.

5.4.3 COST ANALYSIS SUMMARY

The cost analysis will focus on the theoretical build of this structure. The rough calculations of the budget were done using the square footage of the building as well as the major components of the building: appliances, mechanical equipment, and electrical equipment. In the next iteration of the budget, it will contain a breakdown of the concrete, drywall, mechanical, plumbing, casework, specialties, and flooring. A preliminary budget for the building can be seen in Table 5 below. In addition, the Indented Bill of Materials is attached in Appendix Q: Indented Bill of Materials with details regarding the type of material for building envelope, electrical equipment, mechanical equipment, plumbing fixtures, and general appliances.

Table 5. Cost Analysis Summary

	Units	Cost/Unit	Total	Location Multiplier	Total
Building SF	16000	233	3,728,000		
Electrical Equipment	1	50000	50,000		
Appliances	12	2500	30,000		
Elevator	1	69900	69,900		
Laundry Drying	7	1025	7,175		
Laundry Washing	7	1250	8,750		
Mechanical Equipment	16000	1.8	28,800		
Total			\$ 3,922,625.00	1.15	\$ 4,511,018.75

One of the main considerations we have left for the building mechanical equipment is the hot water heater. In addition, we must finalize the façade material of the building to allow for easy constructability that will lower labor costs.

6. MANUFACTURING

6.1 MANUFACTURING SUMMARY

We are delivering architectural plans, mechanical drawings, and a summary of all relevant building information. Architectural plans were produced by the architecture students, Emma Siegel, Angelee Chea, and Anne Kanazawa, and reviewed by architecture professors, Ansgar Killing and Beate Von Bischofinck. The mechanical side of the team are producing mechanical drawings using Revit MEP. The building information was compiled from various software including TRACE 700, DesignBuilder, and REM/Rate.

6.2 MATERIAL PROCUREMENT

Because this is a design-only project, our materials are the software that we are using to model our building, calculate relevant data, and compile a comprehensive design portfolio both for the competition and our sponsors. Certain software is provided to us through the Solar Decathlon, including OneClickLCA and OpenStudio. Other software that we used are provided to us through Cal Poly. This includes DesignBuilder and TRACE 700. The solar PV design software Helioscope is being used in the free trial mode.

Because our materials are only software, we did not need to order any parts. This software is all available to use through Cal Poly, the Solar Decathlon, or free trials.

Table 6. Design Components and Materials Needed

Component	Materials/Software
Revit Mechanical Drawings	Revit
	Revit Family Files: Fan Coil Units
	Revit Family Files: Branch Selector Box
	Revit Family Files: Outdoor Unit
	Revit Architecture File
Solar Layout	Helioscope
Opaque Renderings	Opaque
Whole Building Energy Performance Model	Design Builder
Comprehensive Load Calculations	Trace 700

Table 7. Material Procurement and Budget

Material/Software	Procurement Process	Cost
Revit	Available through Cal Poly virtual labs or student access	\$0
Revit Family Files for LG Components	Downloaded from LG website	\$0
Revit Architecture File	Provided by the architecture side of the team	\$0
Floorplan PDF	Provided by the architecture side of the team	\$0
Design Builder	Available through Cal Poly remote desktop	\$0
Trace 700	Available through Cal Poly remote desktop	\$0
Helioscope	Available in free trial	\$0
Opaque	Available through Cal Poly	\$0
Total Cost		\$0

6.3 FACILITIES AND EQUIPMENT

Because all manufacturing was done virtually, the only facilities we needed was our individual workspaces and the only equipment we needed was our personal computers with access to the Cal Poly Remote Desktop and Virtual Labs.

6.4 ASSEMBLY

6.4.1 SOLAR ARRAY ASSEMBLY

1. Determine the maximum power the site can provide for the current architectural design.
2. Determined required power for HVAC, lighting, and plug loads.
3. Adjust design to achieve net-zero status.
4. Choose the inverter, mounting system, power optimizer, and solar panel module.
5. Determine the performance of solar power system in extreme weather.
6. Design power system for future EV charging station and battery capability.

6.4.2 HVAC SYSTEM ASSEMBLY

1. Use load calculations to select fan coil units.
2. Create spreadsheet tool to determine necessary airflow to meet ventilation standards.
3. Use the airflow to size the ductwork and outdoor DOAS units.
4. Contact DMG representative to get quote for equipment.
5. Determine locations of supply and return diffusers
6. Obtain Revit family files for components from LG website (fan coil units, branch selector boxes, outdoor units)
7. Generate HVAC system diagram that includes piping, ductwork, and equipment locations using Revit MEP.

6.4.3 PLUMBING ASSEMBLY

1. Select toilets, showerheads, faucets, and piping for building.
2. Determine the water heating method for the building.
3. Create spreadsheet of the flow rate and expected efficiency of the fixtures and appliances.
4. Determine the expected average use for fixtures and appliances based on residential data.
5. Determine piping required for fixtures and appliances.
6. Generate plumbing system diagram that includes piping and equipment locations using Revit MEP.

6.4.4 ELECTRICAL ASSEMBLY

1. Select lighting fixtures, switches, and receptacles for the building.
2. Determine number of lighting fixtures, switches, and receptacles for each unit of the building.
3. Create electrical schedules for each unit to determine requirements for the panel board.
4. Generate electrical system diagram including electrical equipment and panel board locations using Revit MEP.

6.4.5 BUILDING ENVELOPE ASSEMBLY

1. Create spreadsheet of various insulation materials that meet the PHIUS standard and building code requirements for 2 x 6 wall studs.
2. Choose façade and internal wall materials.
3. Create several insulation, façade, and interior wall combinations to test in TRACE 700, OpenStudio, and Opaque.
4. Test insulation combinations in TRACE 700 and OpenStudio to determine the energy lost through the building envelope.
5. Weigh out best performing combinations with price to determine the insulation package used for the walls, ceiling, roof, and floors.
6. Create wall assemblies for the insulation using Opaque.

6.5 RESULTS

6.5.1 SOLAR ARRAY ASSEMBLY

The solar PV system was designed using Helioscope. The Helioscope model is shown in Figure 29 and Figure 30. The panels, rooftop HVAC equipment, and general shape of the building were included in the model to accurately predict shading and energy production.

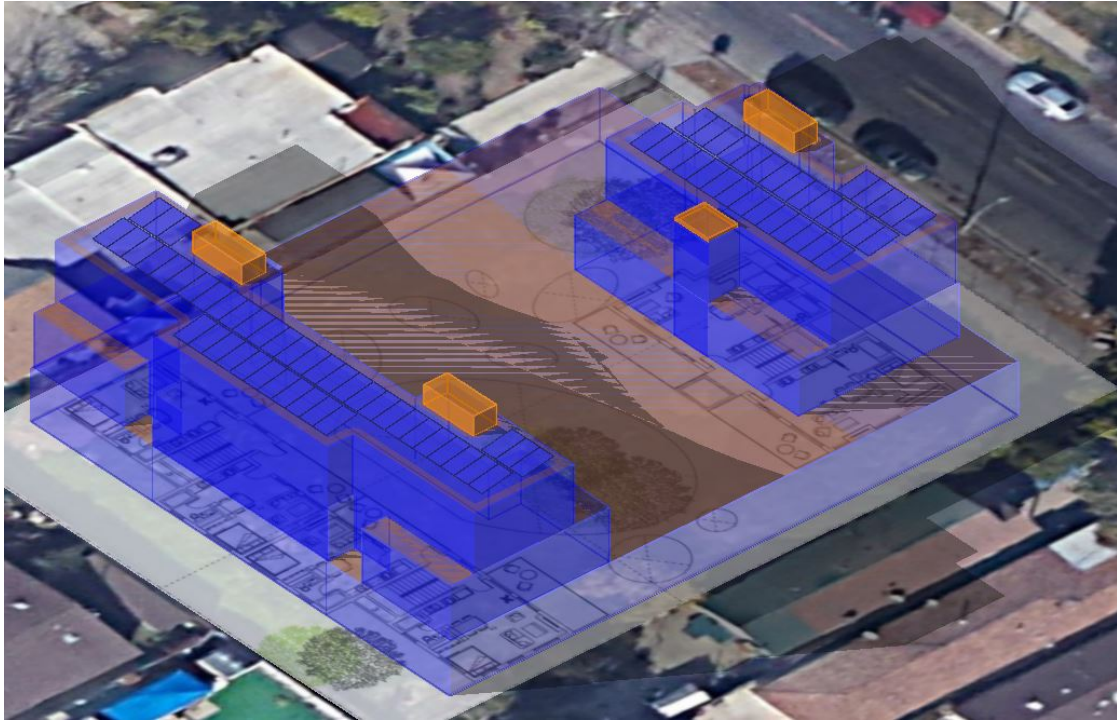


Figure 29. Helioscope Solar Model SE View

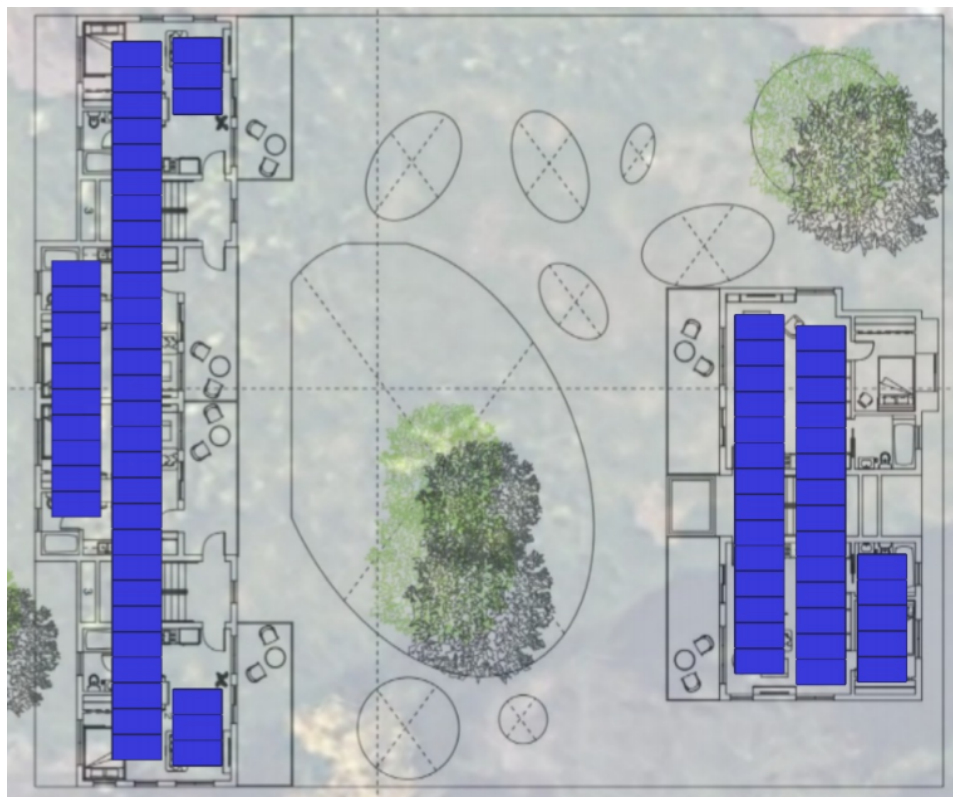


Figure 30. Helioscope Solar Panel Layout Top View

Shown in Figure 31, the panels in the model are set at a 10-degree tilt with 1.5-foot row spacing as this was found to maximize annual energy production. The final design consists of 90 LG 425W panels totaling to a total system size 38.3 kW. The panels are wired in strings of nine (ten strings total) to a single 35 kW string inverter.

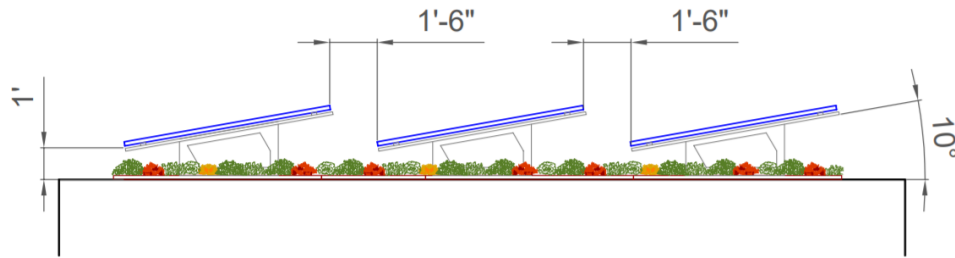


Figure 31. Final Solar Panel Layout Side View

6.5.2 HVAC ASSEMBLY

We performed a preliminary HVAC load calculation in Design Builder to size the equipment. This was before our final Design Builder model, which was used to verify our design. After contacting a sales engineer at DMG, he helped us size the equipment from his database of manufacturers and products. After sizing the equipment, we sized the ductwork based on our preliminary ventilation calculations.

We calculated the ventilation required of each space in the building using Excel. This analysis assumed a 100% outdoor air system and utilized equations and values from ASHRAE Standard 62.1. The results of these analysis can be found below in

We used the information from the required ventilation analysis to size our ductwork using a ductulator, based on 0.08 w.g. of pressure drop. After this, we drew mechanical plans for the entire building. A sample mechanical plan for the second-floor can be found below in Figure 32. The entire set of mechanical plans can be found in the Drawing Package of Appendix U.

Table 8. Note that this duct diameter refers to both the supply and return duct.

We used the information from the required ventilation analysis to size our ductwork using a ductulator, based on 0.08 w.g. of pressure drop. After this, we drew mechanical plans for the entire building. A sample mechanical plan for the second-floor can be found below in Figure 32. The entire set of mechanical plans can be found in the Drawing Package of Appendix U.

Table 8. Ventilation Results

Space	Zone	Ventilation Requirement (CFM)	Duct Diameter (in)
Two Bedroom ADA	Living Room	77	8
	Bathroom	22	4
	Large Bedroom	28	4
	Small Bedroom	25	4
	Total	151	---
Two Bedroom Non-ADA	Living Room	103	8
	Bathroom	22	4
	Large Bedroom	26	4
	Small Bedroom	26	4
	Total	176	---
One Bedroom ADA	Living Room	71	6
	Bathroom	20	4
	Bedroom	24	4
	Total	114	---
One Bedroom Non-ADA	Living Room	69	6
	Bathroom	19	4
	Bedroom	23	4
	Total	111	---
Studio 1	Single Zone	55	6
Studio 2	Single Zone	54	6
Community Space	Single Zone	441	12
Youth Center	Single Zone	274	10
Laundry Room	Single Zone	216	10
Mail Room/Office	Single Zone	67	6
Study Room	Single Zone	64	6

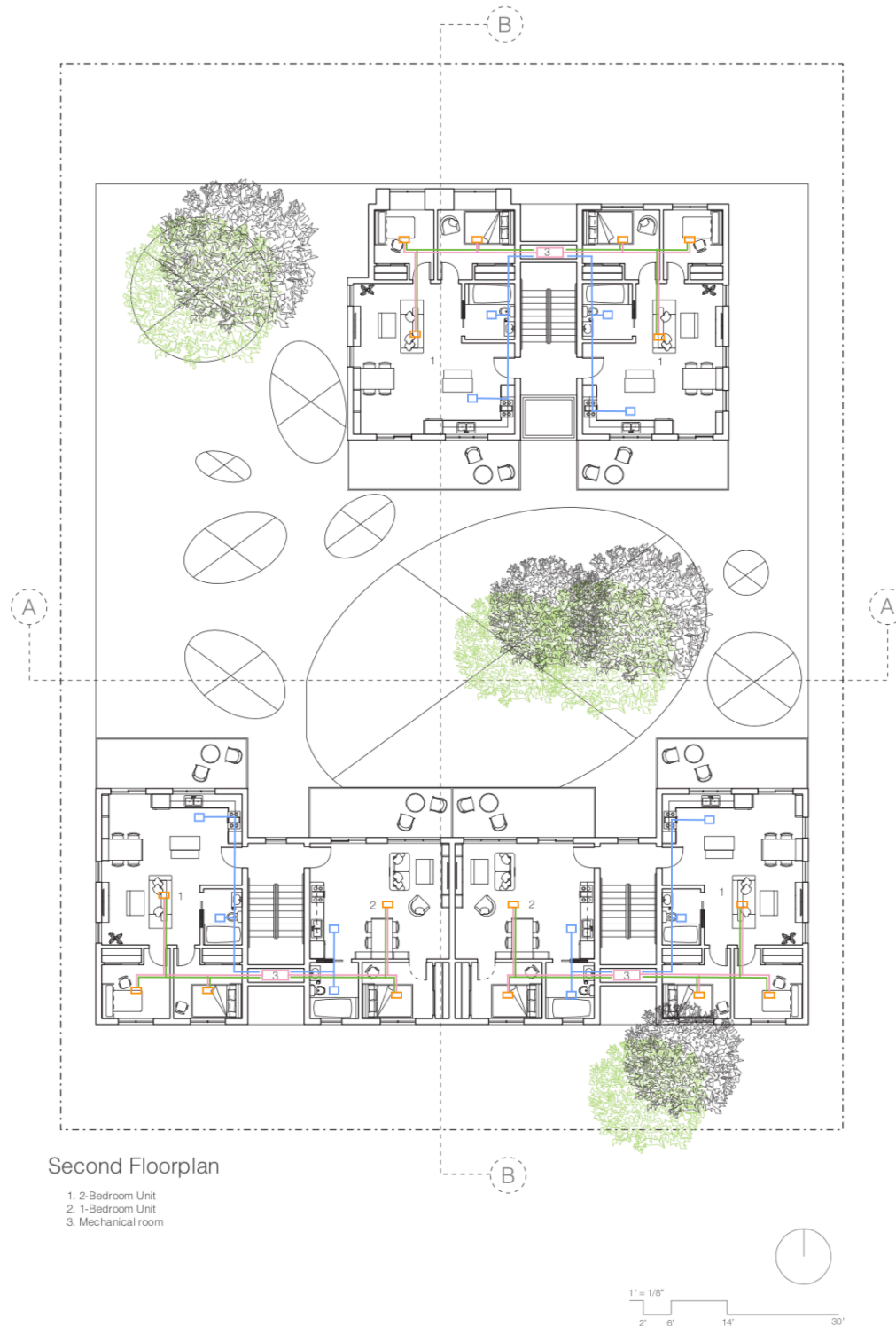


Figure 32. Sample Mechanical Plan of Second Floor

After drawing the mechanical plans for the entire building, we focused on building the Revit model for the two two-bedroom ADA compliant units. Because this is an apartment building and much of the architecture is repetitive, representing two units suffices to show the layout for the other units.

First, we placed the equipment in Revit, including branch selector boxes, fan coil units, return diffusers, outdoor air-intake units, and outdoor condensing units. The first equipment placement can be found in **Error! Reference source not found.**

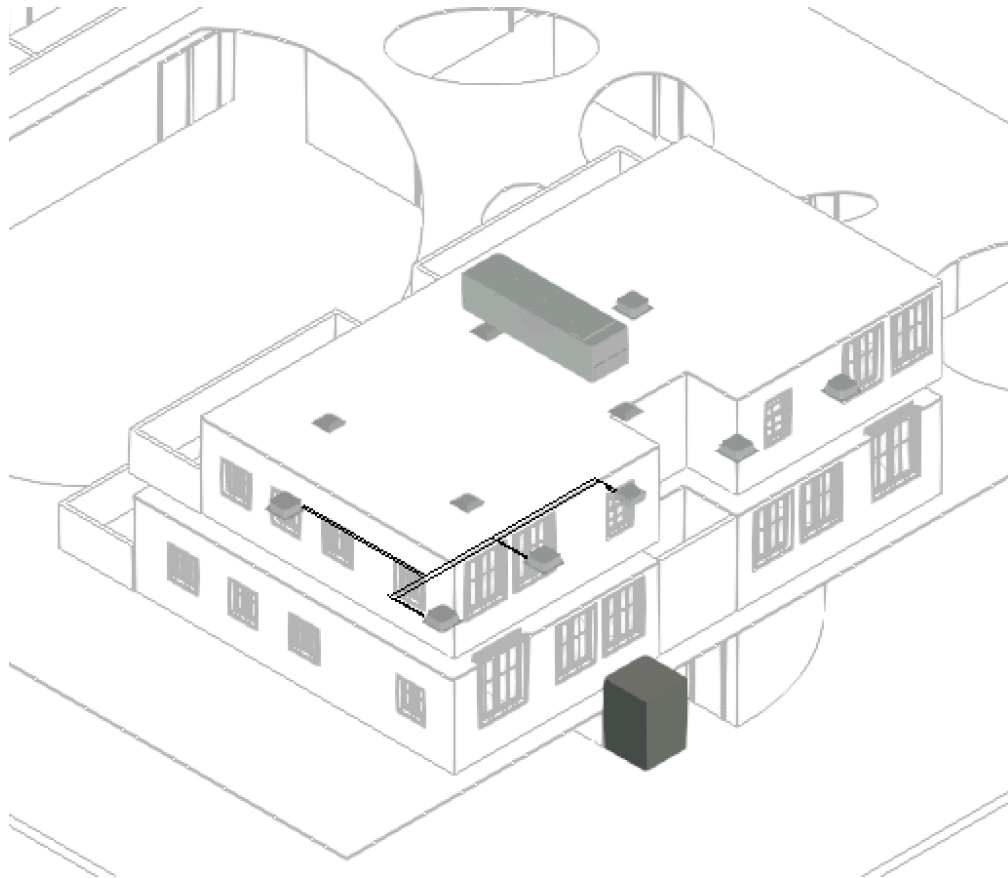


Figure 33. Equipment placement in isometric view

After placing the equipment, we connected them with refrigerant piping. The refrigerant piping placement for the HVAC system can be seen in Figure 34. This required using the engineering manuals from the manufacturer to connect the appropriate ports.

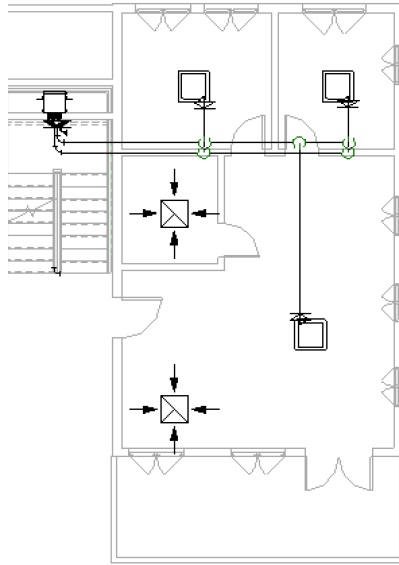


Figure 34. Refrigerant piping placement

After connecting the appropriate refrigerant piping to the equipment, we routed the ductwork. This required us to be very careful not to have any ductwork interfering with each other, other equipment, or refrigerant piping. The ductwork placement can be found in Figure 35.

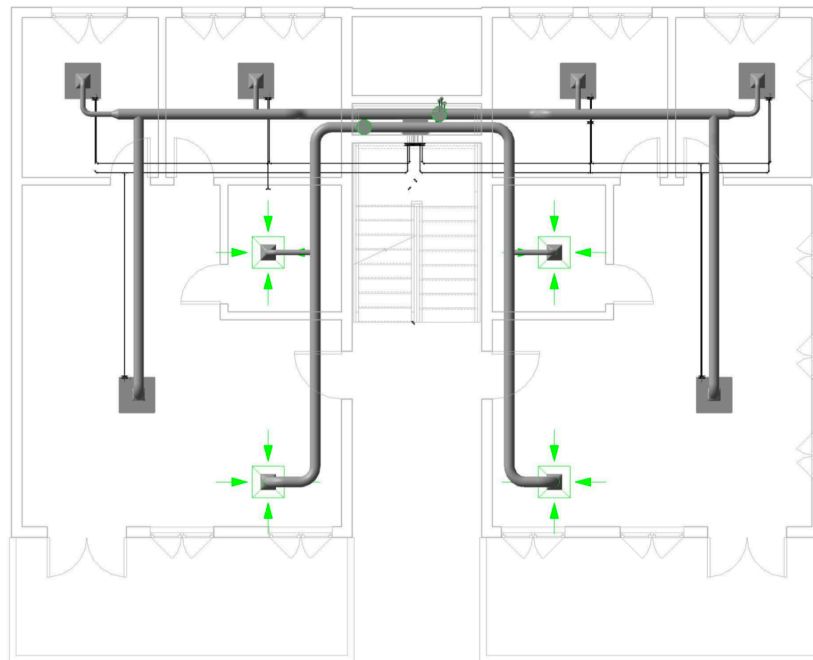


Figure 35. Ductwork placement

The final Revit plans were submitted as part of our Verification Prototype and can also be found in Appendix U.

6.5.3 PLUMBING ASSEMBLY

After selecting plumbing fixtures from the EPA's WaterSense list and receiving fixture layouts from the architecture team, a preliminary plumbing layout was overlaid on top of the building floor plans using AutoCAD. At this point in the process, piping sizes had not been selected, so the main purpose of this step was to get a rough estimate of how the plumbing would be laid out. A sample of this rough plumbing layout can be found in Figure 36. This rough layout shows the second floor of the north building.

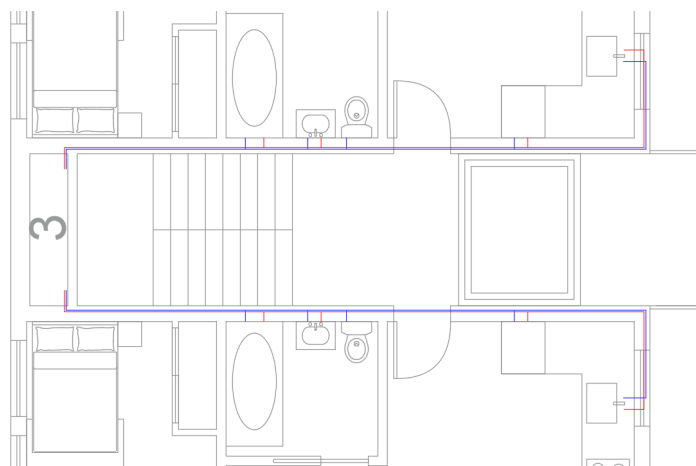


Figure 36. AutoCAD rough plumbing layout

After creating the rough layout, the pipes were sized according to the fixtures' connection sizes, expected flow rate through the pipes, and the 2019 California Plumbing Code. After sizing the pipe, it was decided that each fixture would be supplied with $\frac{1}{2}$ " pipe which branch from a main $\frac{3}{4}$ " pipe for both cold and hot water supply systems.

With the selected pipe sizes, fixture types, fixture locations, and a rough plumbing layout, the design was then brought into Revit MEP for more detailed design. Starting with the existing architectural Revit file, plumbing fixtures were loaded into the software and added to the model. After the fixtures were placed correctly, sized piping was placed connecting the fixtures to cold and hot water supplies. A 3D view of the final plumbing layout can be seen in Figure 37. Additional plumbing plans can be found in Appendix U.

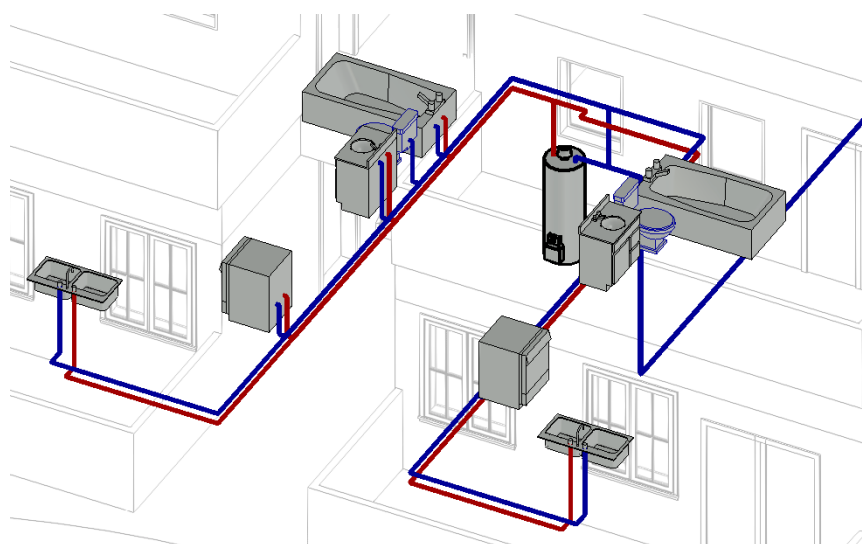


Figure 37. 3D view of final Revit plumbing plan

6.5.4 ELECTRICAL ASSEMBLY

After all household appliances and mechanical systems were determined, we created an electrical load schedule for each of the units. Electrical load schedules, as seen in Figure 38 below, were used to determine the breaker size required for each appliance and circuit. Since the electric range required 208 V, we used a 120/208 V panel board in Revit.

2-bed breaker panel (640-700 SF) left side										
Circuit	items	Phase	No. of Outlets	Power (kW)	Power (kVA)	Volts	Amps Drawn	Required Amps	Wire	Circuit Breaker
1	fridge	1	1	0.36	0.40	120.00	3.33	15	14 AWG	15 A 1P
2	dishwasher	1	1	0.60	0.67	60.00	10.00	15	14 AWG	15 A 1P
3	microwave	1	1	0.70	0.78	120.00	6.48	15	14 AWG	15 A 1P
4	electric range	1	1	8.75	9.72	240/208	40.00	40	8 AWG	40 A 1P
5	living room outlets	1	6	1.44	1.60	120	15.00	15	12 AWG	20 A 1P
6	kitchen outlets	1	2	1.50	1.67	125	15.00	15	12 AWG	20 A 1P
7	bathroom outlets	1	1	1.50	1.67	125	15.00	15	12 AWG	20 A 1P
8	master bedroom outlets	1	5	1.50	1.67	125	15.00	15	11 AWG	19 A 1P
9	bedroom outlets	1	4	1.50	1.67	125	15.00	15	12 AWG	20 A 1P

Figure 38. Electrical load schedule for one of the ADA units.

We used the architectural Revit file to create a base for the electrical plans. The outlets, lighting appliances, and switches were the first to be put in. We decided to use Revit's built-in families for all the electrical fixtures. Due to the limited options with Revit's families, the electrical fixtures used are not true to what is used in our design. Although our plan originally had dimming switches with motion sensors for each room, we used standard dimming switches in Revit. Additionally, the lighting fixture is a generic 100 W flat round ceiling fixture rather than the flush mount 100 W Hampton Bay lighting fixture specified in our Design Portfolio.

An electrical panel was put in on the second floor so that residents can easily access the breakers for their unit. Another electrical panel was put in on the 1st floor that contained a breaker for each unit, making electrical maintenance for a given unit much easier. Circuits for all outlets were then created for the second-floor breaker. Each appliance had its own outlet to prevent overloading a given circuit. GFCI outlets were used for the dishwasher and bathroom outlets to protect the outlets from any external water. The remaining outlets for miscellaneous use and lighting were combined into circuits based on the room the outlets were in. The electrical fixtures can be seen in Figure 39, where the switches are designated by the pink spots and the outlets are labeled with the number of their circuit.

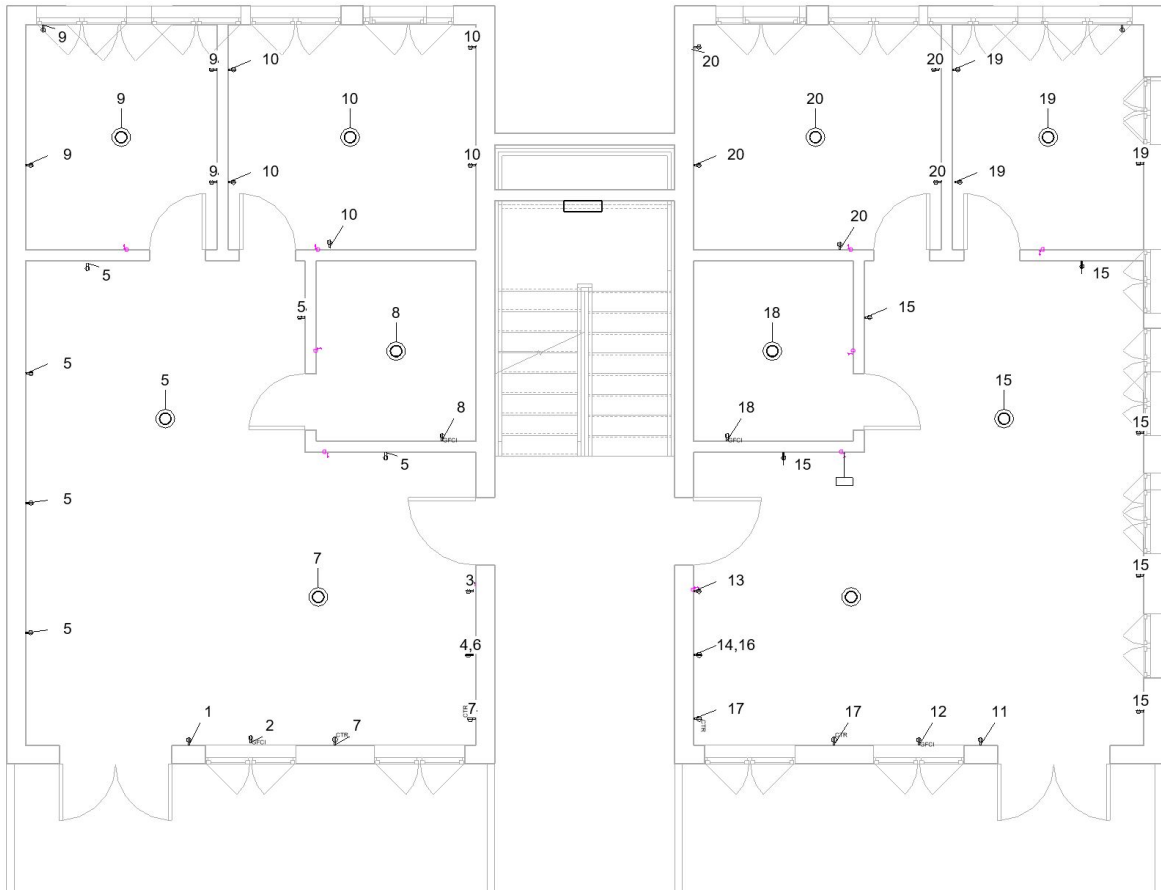


Figure 39. Lighting fixtures, outlets with circuits, and switches for the 2 ADA compliant units.

Once all the circuits were created, we used Revit's suggested wiring to input the wiring for each unit. The last component of the electrical system installed was the conduit. The conduit was laid out to connect the main electrical supply to each electrical panel. The final layout of the electrical system can be seen in Figure 40.

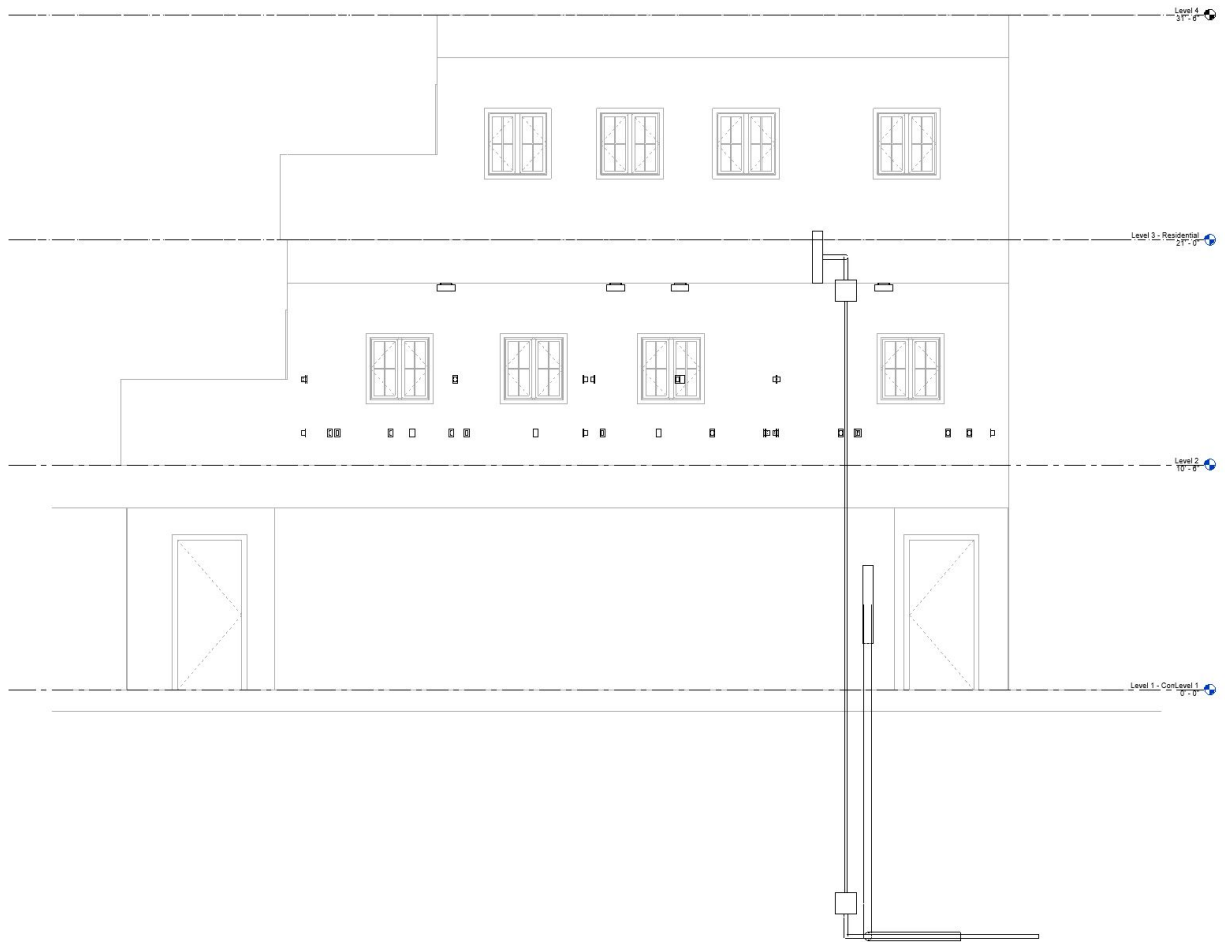


Figure 40. Final electrical layout for the 2 ADA units

6.5.5 BUILDING ENVELOPE ASSEMBLY

We designed the building envelope to create an air-tight, highly insulated thermal control layer. A diagram with the elements of each wall-section was created by the architecture side of the team and can be found in Figure 41.

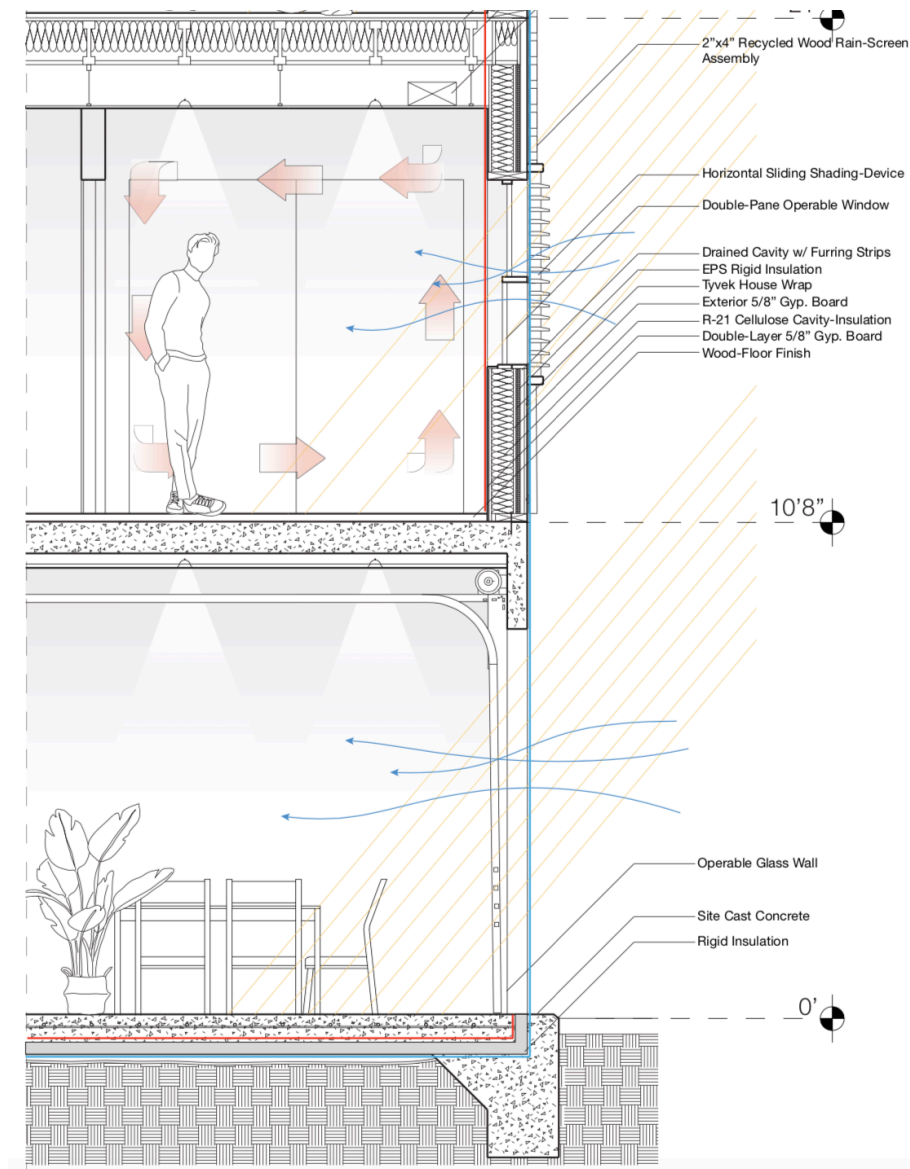


Figure 41. First and Second Floor Wall Sections

The first-floor wall section model includes the precast concrete, latex paint coat, and rigid insulation. The second-floor wall section model includes studs, EPS rigid foam panels, dense-packed cellulose insulation, and exterior gypsum board sheathing. We then modeled the wall sections in Opaque to verify that our wall section met our specifications.

6.6 DISCUSSION

We ran into challenges coordinating the MEP plans in a virtual environment. In industry, MEP plans would be performed by people in the same office who can share files to ensure there were no interference between piping, ductwork, and wiring. Ultimately, due to time constraints, we had to split the MEP plans into mechanical, electrical, and plumbing and assigned different team members to each. Typical industry MEP plans are laid out for the entire building. However, due to time constraints and our lack of experience with Revit, we are creating MEP plans for the two ADA compliant two-bedroom units in our complex.

6.7 RECOMMENDATIONS

For future teams, we recommend using the Revit families supplied by the manufacturer, so it is as true to the real design as possible. Manufacturers almost always have BIM files for their equipment on their websites, which we did not realize until decently far into our Revit model. We also recommend consulting with an industry consultant. Our conversations with a representative from DMG were incredibly helpful in guiding our mechanical layout.

In addition, for the load calculations, we recommend having a shared spreadsheet with the architecture and mechanical team where the gross area of the walls, door, and windows are listed in one area. Consolidating this information in one spreadsheet will streamline the process of conducting load calculations within the TRACE 700 software. This will also visually represent to anyone viewing this project how many rooms and zones there are within the construction.

7. DESIGN VERIFICATION REPORT

Our design verification plan focuses on the analyses and simulations that need to be run for our building's mechanical systems. This includes the mechanical system, elements of structural design, environmental impact, and financial cost of our building. The descriptions of our tests, results, and interpretations of our results are included in this chapter, but we include details about some of our more complicated and important tests (Trace, Design Builder, Helioscope, and Ventilation Excel Calculations) in Appendix S.

7.1 FACILITIES AND EQUIPMENT

Because all these tests were virtual, the facilities of every test were our respective workspaces. Similarly, the equipment we used was our personal computers and necessary software mentioned in the test description. There were no safety risks associated with any of these software tests.

7.2 LOAD OF BUILDING

To determine the heating and cooling loads for our final building design, we will use TRACE 700 and Design Builder. TRACE 700 and OpenStudio will be utilized to determine the efficacy of various insulation combinations. PHIUS and Title 24 standards are guiding our insulation choices. We will use the expected heating and cooling loads in tandem with expected plug loads as a baseline for the power requirement of our PV system. We created templates in Trace (a sample is shown in Figure 42. Room Template in Trace) that represented various occupied spaces in our structure.

Alternative 1

Room description: 3-SOL-L

Templates...

Room: Default

Internal: My Internal Template

Airflow: My Airflow Template

T stat: Default

Constr: My Construction Template

Length: 12.08 ft

Width: 14.83 ft

Floor...: 0 ft

Roof...: 0 ft

☒ Equals floor

Wall...

Description	Length (ft)	Height (ft)	Direction	% Glass or Qty	Length (ft)	Height (ft)	Window
3-SOL-L N	12.08	9	0	0	1	3.36	5
3-SOL-L W	14.83	9	0	0	1	4	4
	0	9	0	0	0	0	0

Internal loads...

People: 200 sq ft/person

Lighting: 0.7 W/sq ft

Misc loads: 350 W

Airflows...

Peop-based: 6.5 cfm/person

Area-based: 0.078 cfm/sq ft

Cooling VAV min: % Clg Airflow

Heating VAV max: % Clg Airflow

Single Sheet | Rooms | Roofs | Walls | Int Loads | Airflows | Partn/Floors

Figure 42. Room Template in Trace

Similarly, Design Builder also requires the user to build the templates. In this software, the templates were broken into types rather than spaces (for example activity level, construction, lighting, etc.). A sample construction template can be seen in **Error! Reference source not found.** below.

Layout | Activity | Construction | Openings | Lighting | HVAC | Generation | CFD

Construction Template

Template: Project construction template

Construction

- External walls
 - Below grade walls: Residential Walls
 - Flat roof: Flat roof - State-of-the-art - Medium weight
 - Pitched roof (occupied): Project pitched roof
 - Pitched roof (unoccupied): Project unoccupied pitched roof
- Internal partitions: Project partition
- Semi-Exposed
 - Semi-exposed walls: Project semi-exposed wall
 - Semi-exposed ceiling: Project semi-exposed ceiling
 - Semi-exposed floor: Project semi-exposed floor
- Floors
 - Ground floor: Slab-On-Grade, Unheated, Fully Insulated, R-15.0
 - External floor: Project external floor
 - Internal floor: 25mm wooden floor blocks

Figure 43. Construction Template in Design Builder

After generating the templates for our building, we generated the building geometry.



Figure 44. Design Builder model NW view

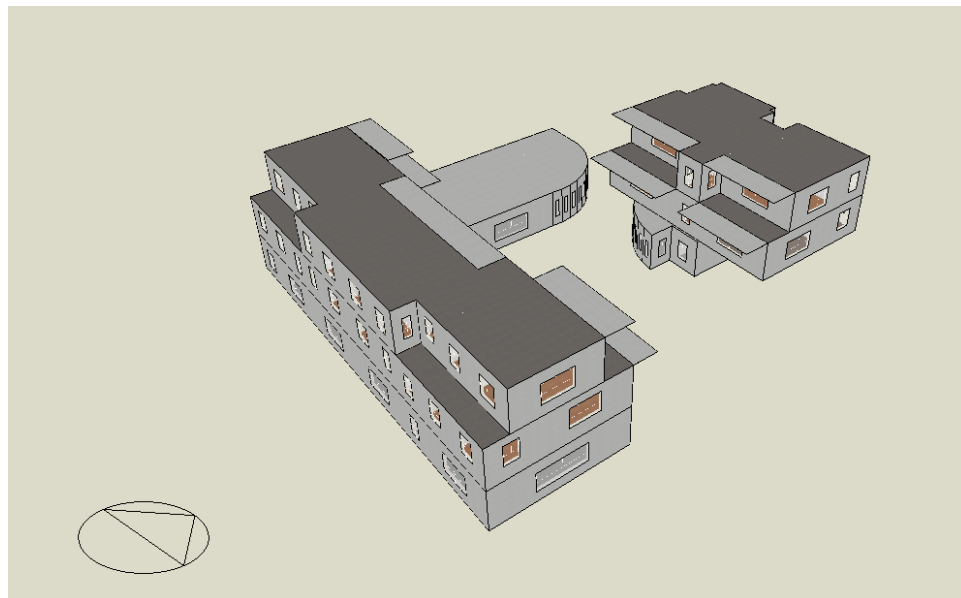


Figure 45. Design Builder model SE view

These tests confirmed certain aspects of our design's performance, while also allowing for the selection of appropriate equipment. The results from our tests can be found below in Table 10.

Table 9. Design Builder and Trace 700 Results

	Total Design Heating Capacity (kBtu/hr)	Total Design Cooling Capacity (kBtu/hr)
Design Builder	108	174
Trace	93	134
Percent Difference	14.9%	25.9%

This test was to confirm our building load calculations and compare the results from two building energy performance software. We found that the results varied between about 15% and 30%, with cooling capacity varying more so than heating capacity. This is most likely due to differences in default settings, assumptions, template, and data that each program uses, although both are built on the EnergyPlus backbone. The results from this test also indicate that we oversized our previous equipment and would need to reiterate the process of HVAC equipment selection to generate accurate equipment selection. For future teams, we recommend using the higher design capacity to size the equipment to be conservative.

7.3 SOLAR ANALYSIS

Our solar PV system was simulated in Helioscope to determine our annual on-site power production. Helioscope takes Typical Meteorological Year (TMY3) radiation and temperature data for our location and uses 3D modeling to assess the shading conditions on the building site. The building geometry (seen in **Error! Reference source not found.** below) determines the shading and optimal solar design for the specific building.

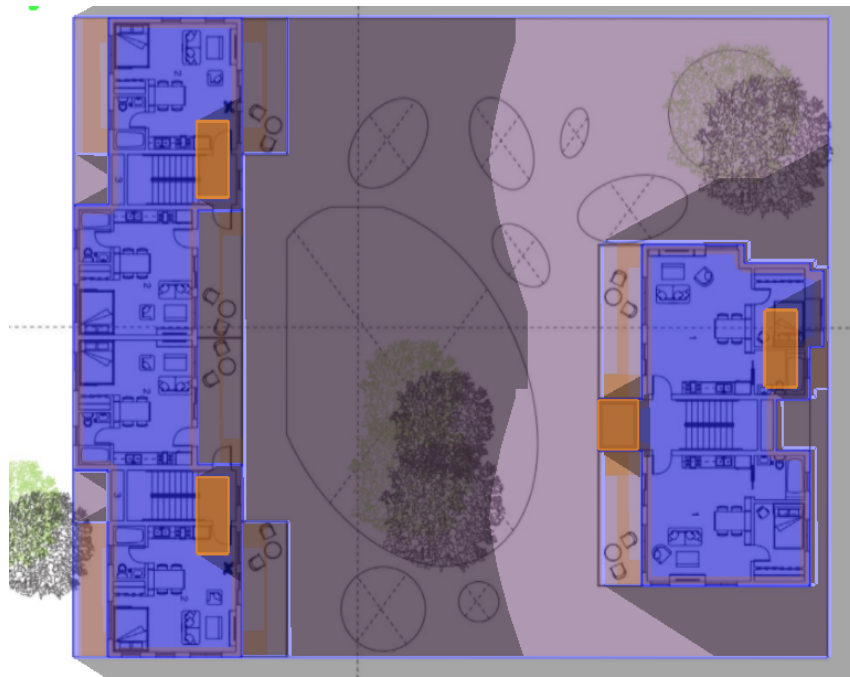


Figure 46. Top View of Building Geometry with “Keepouts” Shown in Orange

The screenshot shows the 'Final Design' window in Helioscope. It includes a 'Preferences' link, a 'Showing Array' button, and tabs for 'Mechanical', 'Keepouts', 'Electrical', and 'Advanced'. The 'Mechanical' tab is active, displaying settings for 'Field Segment 4'. The array is identified as 'LG, LG425N2W-L5 (425W)'. The racking is set to 'Fixed Tilt Racking'. The height is 21 ft, azimuth is 180°, and tilt is 10°. Under 'Automatic Layout Rules', the frame size is 1 up by 1 wide, default orientation is Portrait (Vertical), row spacing is 1.5 ft, span/rise is 1.3, module spacing is 0.04 ft, GCR is 0.82, frame spacing is 0 ft, and a 'Time of Day' link is present. The setback is 1.5 ft. An 'Alignment' section at the bottom shows three icons for different array orientations.

Figure 47. Data Setting Input for Helioscope

The software takes internal efficiencies into account and then runs a simulation to determine how much power is being produced for each hour throughout the year. The California Solar Permitting Guidebook, which contains all Title 24 codes concerning solar power and solar water heating, will guide the solar array designs.

The Helioscope simulation estimated that the system would produce 67000 kWh/year. The monthly distribution of energy production is shown in Figure 48.

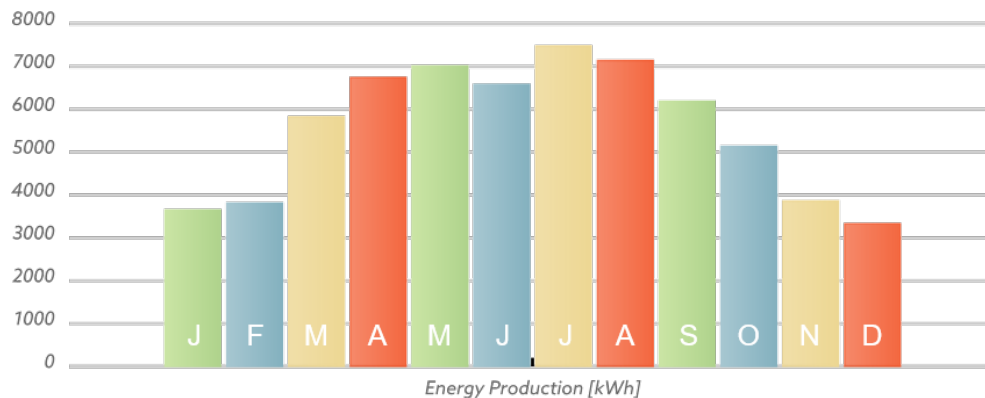


Figure 48. Monthly Estimated Energy Production Throughout a Typical Year

7.4 BUILDING ENVELOPE ANALYSIS

The envelope was analyzed using Opaque software that determined the R-value of our entire wall, including studs, insulation, and façade. By changing the input parameters regarding our envelope such as window placement and type, we will observe how these decisions impact our load calculations. From our Opaque analysis, we found that our first-floor wall R-value was R-29, our second/third floor wall R-value was R-20, and our foundation R-value was R-17. Title 24 dictates that the R-value must be at least R-21. This shows that the first-floor wall does not pass Title 24 Energy Code Compliance, but the second and third floor walls do. Furthermore, the second and third floor walls actually surpass the PHIUS standard. This analysis showed us that concrete is not a sufficient insulator, so we would need to increase the insulation on the first floor if we were to redesign the wall. This also showed us that the wall assembly for the second and third floors is very efficient and therefore, we recommend a similar assembly to future teams.

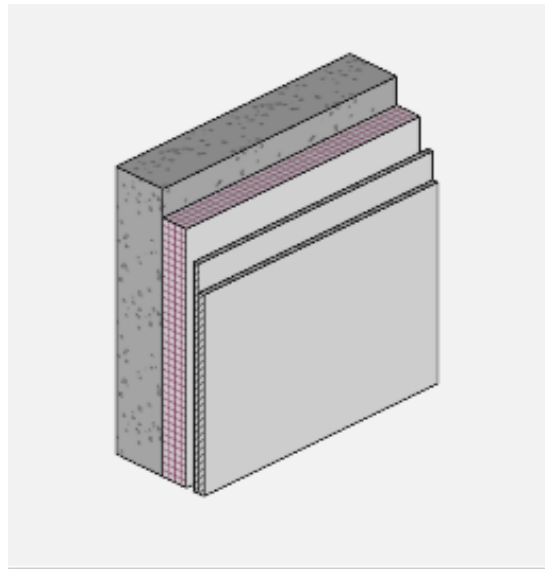


Figure 49. Opaque rendering of first floor exterior wall

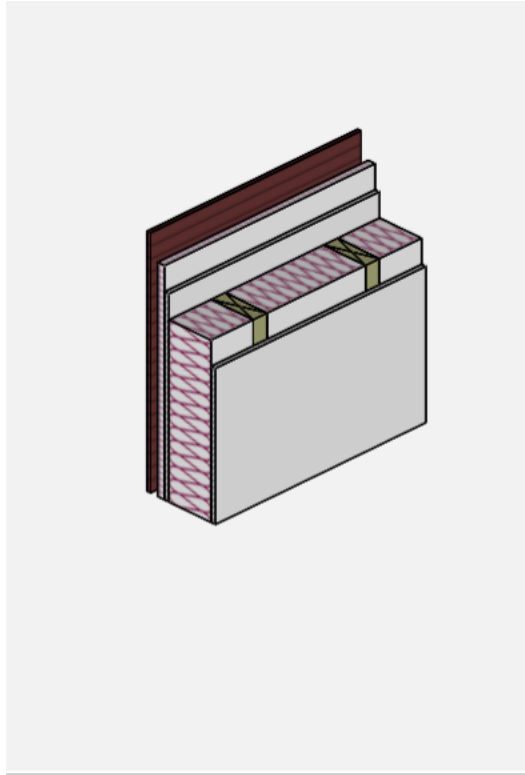


Figure 50. Opaque rendering of second floor exterior wall

7.5 ENERGY PERFORMANCE

An iterative process was used to evaluate the effect that changing various aspects of the building envelope and lighting systems have on the energy usage of the building. A baseline was established with the building geometry developed by the architecture team and the IECC 2000 energy code templates in design builder for construction, lighting, openings, and HVAC. After the baseline was established, one option in the table below was implemented and the simulated EUI of the building was recorded to evaluate the change in energy consumption. Only one option is changed at a time to isolate the effects of that specific change. This process allows us to see which upgrades are worth the effort and cost to implement in the final design.

Table 10. Individual building upgrades used to guide decision making process.

	Option 1	Option 2	Option 3	Option 4	Option 5
Walls	R-20	R-35	R-45	---	---
Roof	R-30	R-45	R-60	---	---
WWR	18%	30%	50%	70%	---
Lighting	Low Standard	W/ linear control	Best Practice	LED	W/ linear control
Windows	Double glazing	DG – interior shading	DG – exterior shading, 1.5m	Triple glazing	---

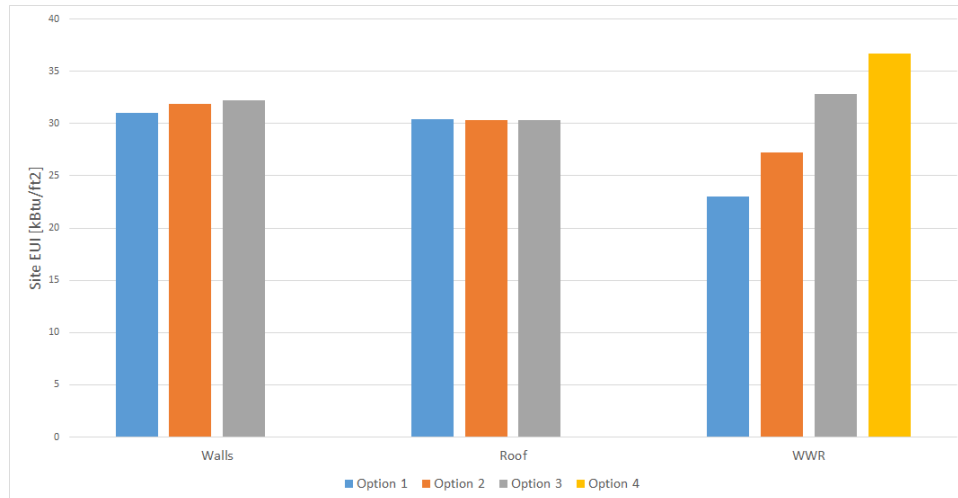


Figure 51. Results of simulations for the wall, roof, and WWR sections.

An interesting trend with the wall insulation is that the higher the insulation value is, the higher the EUI. This is due to the walls increased ability to retain thermal energy inside the building and the generally greater need for cooling than heating in the warm LA climate. This trend does not hold with the final building because the DOAS system is able to remove the excess heat during cooling hours without the need for active cooling. The roof area is relatively small compared to the wall area so upgrades to the roof insulation provide poor reduction in EUI. Window-to-wall ratio had the widest range of energy performance out of any other building system. The small the window area, the better the energy performance.

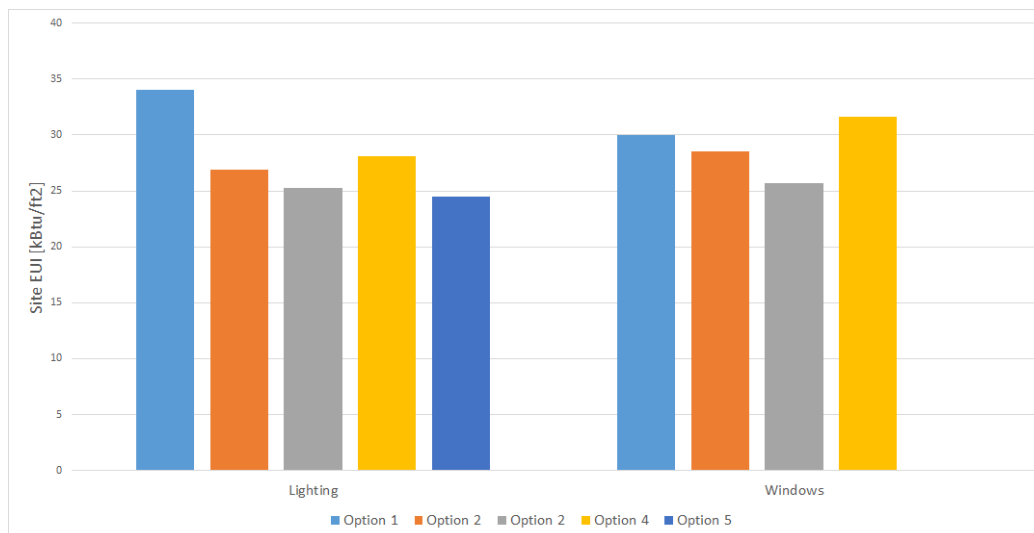


Figure 52. Results of the simulations for the lighting and window options.

Lighting systems had the second largest range of energy performance between options behind WWR. Putting a linear control system in every room provided a similar reduction in EUI as changing low standard lightbulbs to standard LED lights. Linear control systems reduce energy consumption but would be expensive to put in every room. Using interior or exterior shading over a double-glazed window performed better than just a triple-glazed window and at a much cheaper price point.

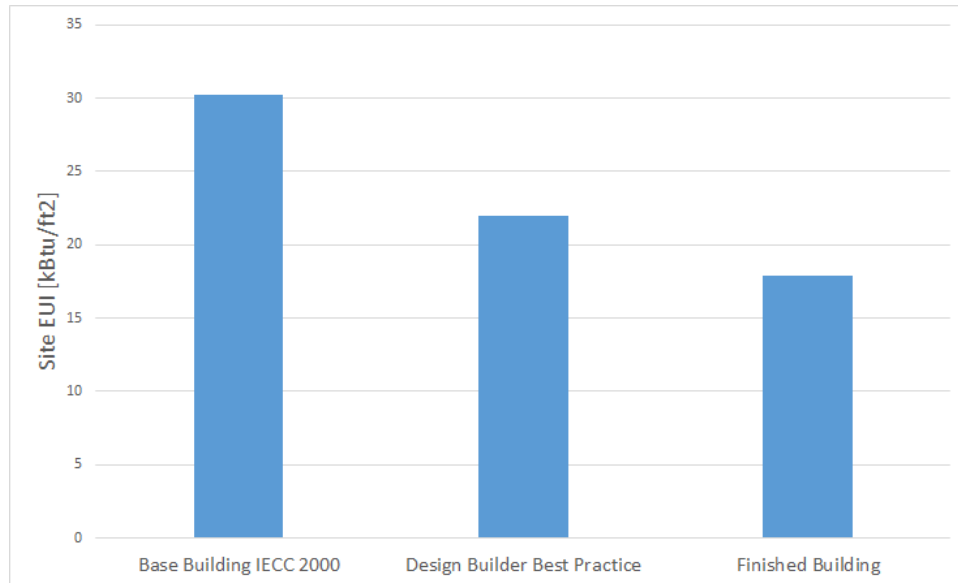


Figure 53. Comparisons between the base building with IECC 2000 energy code standards, the “best practice” options defined by Design Builder, and the final design choices.

By changing the construction, lighting, openings, and HVAC templates from IECC 2000 to “best practice” as defined by Design Builder, the EUI was reduced by 27.2%. The final design created further reduced the EUI from the base case by 40.8%. These reductions in energy consumption reduce the number of solar panels that are required to reach net-zero energy.

7.6 LIFE CYCLE

The construction management part of our team, Grace Brekke, calculated the life-cycle cost of our structure broken down by stage and then by material. This gives us particular insight into the payoff period of our design decisions as well as information about our material selection. The results of our life-cycle analysis can be found in Table 11 and After this, she calculated it by material, found in **Error! Not a valid bookmark self-reference..**

Table 12. Grace first calculated it by life stage of the building, found in Table 11.

Table 11. Life Cycle Analysis by Life Stage

Life Stage	Life Cycle
Materials	84.8%
Transportation	7.6%
Construction	3.5%
Waste Processing	4.1%

After this, she calculated it by material, found in **Error! Not a valid bookmark self-reference..**

Table 12. Life Cycle Analysis by Material

Material	Life Cycle
Doors/Windows	38.1%
Ready-Mix	33.5%
Insulation	21.4%
Wood	7%

The results of this test indicate that much of the life-cycle cost of our building is an up-front materials cost. It also confirms that our selection of locally sourced materials resulted in a relatively low transportation carbon impact. In terms of materials, a major finding was that the concrete was a significant source of life-cycle cost. Although doors/windows and insulation were also relatively high, these are absolutely essential to the building. Concrete, on the other hand, could have been cut down by eliminating the large concrete podium on the design. It seems that the thermal massing it provides, as well as architectural aesthetic, is not sufficient to offset its environmental and financial cost. Using more wood-frame construction would be result in a lower life-cycle cost.

7.7 BUDGET ANALYSIS

Our project budget limit is based on previous low-income public housing budgets. We determined our project budget with RSMeans. We found that our building would cost \$4,511,018.75 to construct. This is 12.5% more than a minimally code compliant building because of the expensive energy efficient measures we included in our building. This was an expected difference because a highly efficient building with PV array will have a higher up-front cost in exchange for lower operating cost. If this building were to actually be built, the builders could apply for special low-income housing grants from the city to reduce the cost.

7.8 WATER CONSUMPTION

Water consumption was evaluated by using the flow rates of each fixture and the average use of each fixture. According to California law, the water consumption must be less than 55 gallons per day per person, but we will aim to minimize the water consumption as much as possible while keeping the design cost-effective. We found from our tests that the daily consumption of water per person was 48 gallons. While this is compliant with California law, we were slightly disappointed that it was not significantly lower than code compliance because of our selection of low-flow fixtures.

7.9 SPECIFICATIONS TABLE

Table 13 shows our final specifications table updated from our previous specifications table, Table 3. Our previous specifications table reflected some of our previous design (when we were designing a single-family home), which we adjusted to reflect our attached housing design. We also changed the table to reflect the specifications that research indicated were most relevant to our design. We eliminated some of the specifications related to the theoretical design that we could not test (including time to construct, structural analysis, and appearance survey), as well as certain elements that would normally be set by on-site building managers (including air changes/hr and indoor humidity). We also added certain specifications that more accurately reflect the performance of our building, including life cycle assessment, water usage in gallons, and total energy generation.

Table 13. Updated Specifications Table

Spec #	Specification Description	Requirement or Target (Units)	Actual	Tolerance	Risk	Compliance	Pass/Fail
1	Energy Use Intensity (EUI)	15 kBtu/sqft/year	22.91 kBtu/sqft/year	Min.	M	A, S	Pass
2	Energy Generation	65,000 kWh/yr	67,000 kWh/yr	Min	H	A, S	Pass
3	Insulation Efficiency	R-20	First Floor Wall: R-20 Second Floor Wall: R-29	Min.	L	S	Pass
4	Cost Analysis for Project	\$4.5 million	\$4,511,018.75	Max.	H	A	Pass
7	Environmental Impact Analysis	300	79 kg CO ₂ e/m ²	Max.	H	A	Pass
8	Lighting Power Density	0.034 W/sqft	0.025 W/sqft	Max.	L	A, S	Pass
11	Cost of Mechanical Systems	\$100,000	\$280,320	Max.	H	A, S	Fail
12	Size	30,000 sqft	11,875 sqft	Max.	L	A	Pass
	Water Usage	55 gal/person/day	48 gal/person/day	Max.	L	A	Pass

As seen in Table 13, we passed the majority of our specifications. We exceeded the EUI, generated more energy than we consumed (indicating that we achieved net-zero status), had a highly insulated building envelope, had a low embodied carbon environmental impact, had low lighting power density, low water usage, and adhered to the competition guidelines for size. We were not on our budget, but this was only \$11,018.75 over budget, which we determined was acceptable for our estimation due to rounding, estimates, and changes in labor costs from year to year. We were far over budget on our mechanical system, most likely because we had to buy so many outdoor units to span the building. However, because we were still approximately on budget for the entire building, we deemed this acceptable as this indicated that we made up the difference in other parts of the budget.

7.10 RECOMMENDATIONS FOR FUTURE TESTING

We recommend setting deadlines for architectural work so that the load calculations and building energy performance modeling can be performed early in the design process. Because our team was still iterating on the architectural design, we had to use preliminary designs to size equipment and then later go in and model the final design after the competition. This would also allow final solar testing to be performed with data that reflects the final architectural design.

We highly recommend taking one or both of the courses offered by Cal Poly that teach how to use Design Builder or Trace. We lacked formal training in this software, which made it very difficult to ensure we were on the right track or that our modeling was accurate. This modeling software were very comprehensive and detailed in their inputs. If you do not know the correct inputs or make assumptions when it is not appropriate, then you will get an inaccurate building model. This is most likely why our final Design Builder model (performed after a team member had training with the software) was so different from the preliminary Design Builder model performed early in the design process. Similarly, the training provided by the Solar Decathlon for REM/Rate, Ekotrope, and OpenStudio should be used. Prior to building the Trace model, we recommend building an Excel document with the room take-offs. This is one file that contains all the necessary details of the building to accurately model it in Trace. When possible, we advise using traditional software like Excel, as we found this was a very helpful software in our process.

8. PROJECT MANAGEMENT

The Solar Decathlon team developed a structure around the Microsoft platform to see the completion of the Solar Decathlon design competition. Utilizing Outlook, Teams, and OneDrive, we ensured that each teammate was responsible for their respective tasks. During fall quarter, we focused on researching all the aspects of the competition and the potential strategies to develop our net-zero energy construction. From the end of fall quarter until the end of winter quarter, we began collaborating with architecture, construction management, and city regional planning students, to start designing the attached housing development. The verifying calculations for loads and energy modeling were completed during the end of winter quarter. Then at the beginning of spring quarter, we presented our final design portfolio to the juries of the competition. Testing and designing are still in progress for delivering our final report at the end of Spring 2021.

8.1 METHOD OF APPROACH

The team consisted of five mechanical engineering, three architecture, one construction management, and one city regional planning students. One mechanical engineering student was designated to be the project manager of the team. Every week there were four meetings: one with architecture and city regional planning, one with mechanical engineers, one with project sponsors, and one general meeting with every team member. In addition to these meetings, incorporating the weekly status report helped maintain the productivity and efficiency throughout the project.

Because the scope of the project was very large, delegating tasks were vital to the completion of the competition. The architecture students had complete creative freedom throughout the project, so they generated the floor plans and building layouts of our development. The mechanical engineering students were tasked to select the MEP systems, which includes the heating ventilation and air-conditioning system, electrical systems, and the plumbing systems, as well as the building science layers (insulation and wall layers). The construction management student was tasked to develop the life cycle, carbon impact of the building and the overall budget of the project. The city, regional planning student was tasked with the research regarding building codes and regulations of the city we were building in as well as the template of our design portfolio. With the delegation of tasks and the role of the project manager, we were able to complete the major deadlines of the project listed in, leading up the submission of the design portfolio and final presentation, where

Table 14 contains the specific week-by-week details leading up to the major submissions.

Table 14. Week-by-week Schedule to Solar Decathlon Completion

	Architecture (ARCH)	Mechanical Engineering (ME)	City Regional Planning (CRP)	Construction Management (CM)	All-Team
2/15-19	Refine renderings, final poster layout	Meeting with DMG, Jason (HVAC equipment selection), water heating system chosen and developed	Templates for portfolio documents created	First iteration of budget	Project Proposal Submitted
2/22-26	Physical model preparation and presentation materials for finalist round	Analysis: HVAC Load Energy Performance Solar Energy Performance Electrical, Lighting Plumbing (EnergyStar) Envelope (PHIUS+2021)	Community /Site analysis	Cost analysis	
3/01-3/05	Presentation materials for finalist round	Analysis: HVAC Load Energy Performance Solar Energy Performance Electrical, Lighting Plumbing (EnergyStar) Envelope (PHIUS+2021)	Portfolio template	Life-cycle cost estimation	Interdisciplinary Review
3/08-3/12	Presentation to college, Final review	Start modeling HVAC ductwork and pipework and plumbing on drawings		Environmental impact	
3/15-3/19	Architecture to add mechanical/plumbing systems	Coordination with HVAC and ARCH			Interdisciplinary Review
3/22-3/26	Coordination, Finalize all details for design	Final coordination with HVAC and ARCH			Final Interdisciplinary Review
3/29-3/30	Final review before submission	Final review before submission			Design Portfolio Due
Softwares we are using:	Rhino Revit Climate Consultant Sefaira	Trace 700 Design Builder Open Studio HelioScope Energy Star PHIUS+2021	InDesign	One Click LCA RS Means	Microsoft Teams Outlook Microsoft Project

9. CONCLUSION

This document is intended to define the scope of the project and provide updates to the design process and the choices made. The goal of our project is to design affordable attached housing for low-income areas of California that meet net-zero energy standards while competing in the 2021 Solar Decathlon Design Challenge. Our senior project group and fellow competition teammates from the Architecture, City Regional Planning, and Construction Management departments used. Using our prior knowledge, background research, and design intuition, we met all the goals set out by the competition requirements. The final deliverable of the competition was the Final Design Portfolio on March 30, 2021.

We found that our integration of the local social conditions into our design was successful and a highlight of the project. Similarly, consideration of the local climate and environment performed well in the competition (e.g. consideration of dense urban environments, pollutants, and native plants). Our VRF system performed well and generated energy savings, but was not as creative as it seemed the jurors would have preferred. Our building envelope provided a highly insulation thermal control barrier, but we found that more focus on newer building technology might have performed better at the competition. Overall, we designed a very practical and buildable structure, but lacked some of the creativity that the jurors seemed to be looking for.

During our design process, we ran into some issues with workflow, in particular, waiting for certain elements of the architectural design to be finalized so we could perform energy modeling or size and place the equipment. However, this is very representative of the industry experience, and by communicating continuously with other disciplines, we were able to mitigate this issue. We found communicating with industry experts and professors with expertise in building energy performance modeling, solar design, and HVAC design was invaluablely helpful. By reaching out early in the design process, we were able to make several very important connections who either offered their expertise or offered to connect us with someone else who could help us.

We designed an affordable, net-zero attached housing structure that satisfied all and even surpassed some of the requirements of the competition. We submitted the Final Design Portfolio, 20-minute video presentation, and competed in the Solar Decathlon competition weekend (albeit virtually). Our design performed strongly and was a finalist in our division, but it was not selected as the winning design. Nonetheless, we learned a lot about designing net-zero structures, solar design, and energy efficient mechanical design.

9.1 RECOMMENDATIONS

We have several recommendations for future teams at Cal Poly who are trying to compete in the Solar Decathlon. These include recommendations regarding the structure of the team, technical aspects of the design, and succeeding at the competition.

In terms of project management, teams should be assembled early and begin with a strong design direction. Because we started as team of mechanical engineers in what is mainly an architecture competition, we had very little direction until we were able to find architecture students to join our team. In winter quarter, we were also able to find city & regional planning as well as construction management students to participate. Having the entire team assembled at the very beginning would have given us more time to finalize certain elements of our design early so we could get started on the mechanical design or solar layout. In particular, we found that having multiple construction management students would have made a stronger team. Several teams at the competition had multiple (if not mostly) construction management students. Because they learn about eco-friendly construction methods and materials, they have a significant wealth of knowledge about some of the more niche aspects of the competition (e.g. source control, embodied carbon impact, etc.). Furthermore, this would have alleviated the burden on the single construction management student on our team, as she was the only one who had any experience doing a budget analysis and life cycle assessment.

In general, having a larger team seemed to be advantageous (the winning team from our division had 38 students on it), although this would pose a significant project management obstacle. We also recommend having a strong team lead who is willing to dedicate a significant amount of time to the project and has strong communication and organizational skills. We had this on our team and felt this was integral to our success. Communication and organization from all members were also essential to completing our design. Having clearly defined deliverables from every team member, with appropriate time given for each task, helped us complete the many modelling, testing, and design stages on time. We recommend contacting industry professional and professors with expertise in the relevant fields early and communicating regularly with them throughout the project. We found a wealth of people who were willing to help us and offer their unique expertise to our project. The Solar Decathlon also offers the option of collaborating with an industry partner. If you wish to compete with an official Solar Decathlon industry partner, they will provide you with the brief of what they want you to design and guidance on specifications like budget, site, and minimum energy performance. While this does provide more structure than designing completely from scratch, it does significantly limit the team's creative license on the design.

In terms of technical recommendations, we found that using local materials significantly decreased the embodied carbon impact associated with the transportation of construction materials. We also recommend integrating designing the structure for the characteristics of the local climate and environment. For example, our area had high levels of pollutants and the urban heat island effect, so we focused certain elements of our engineering and architectural design on mitigating these. Our integration of native plants to the area in the landscaping was successful in demonstrating our consideration of the local environment. The design should also include consideration to the local social conditions (e.g. lower incomes, levels of education, etc.). We recommend analyzing each material for source control, as this was something the jurors focused on heavily when reviewing our project.

We learned a lot about the structure of the competition and the relative weight that jurors place on various design elements. Because the Solar Decathlon is a research-based competition, we saw that the jurors really valued creative solutions, even if they were not entirely feasible. The winning team from the attached housing division had a very creative HVAC solution, which seemed to be the main attraction of the engineering design. They also showed significant integration with the needs and characteristics of the area they were building in. Another key takeaway from the competition weekend is to justify every aspect of our design. In particular, jurors focused on the justification for the amount of concrete that we integrated into our design. Concrete is not a very good insulator and has a relatively large embodied carbon impact. We decided that this was outweighed by the thermal massing the podium provided, cheap cost of construction, and division of public and private areas of the structure. However, having numeric justification for this would have made our argument stronger. Much of the competition weekend is focused on your ability to defend your design choices. Keeping a document of your choices, motivations behind those choices, and comprehensive analysis to back up your design decisions makes this easier. Although we did this for much of the design (e.g. analyzing the difference in cost and energy usage of solar collectors vs heat pump water heaters, testing different windows on energy performance, etc.), the smaller nature of our team prevented us from doing this for every single design decision. This is where having a larger team would yield an advantage.

More detailed recommendations for future teams can be found in our User Manual for future teams competing in the Solar Decathlon, in Appendix Y, as well as our final recommendation write-up to our sponsors in our Verification Prototype folder.

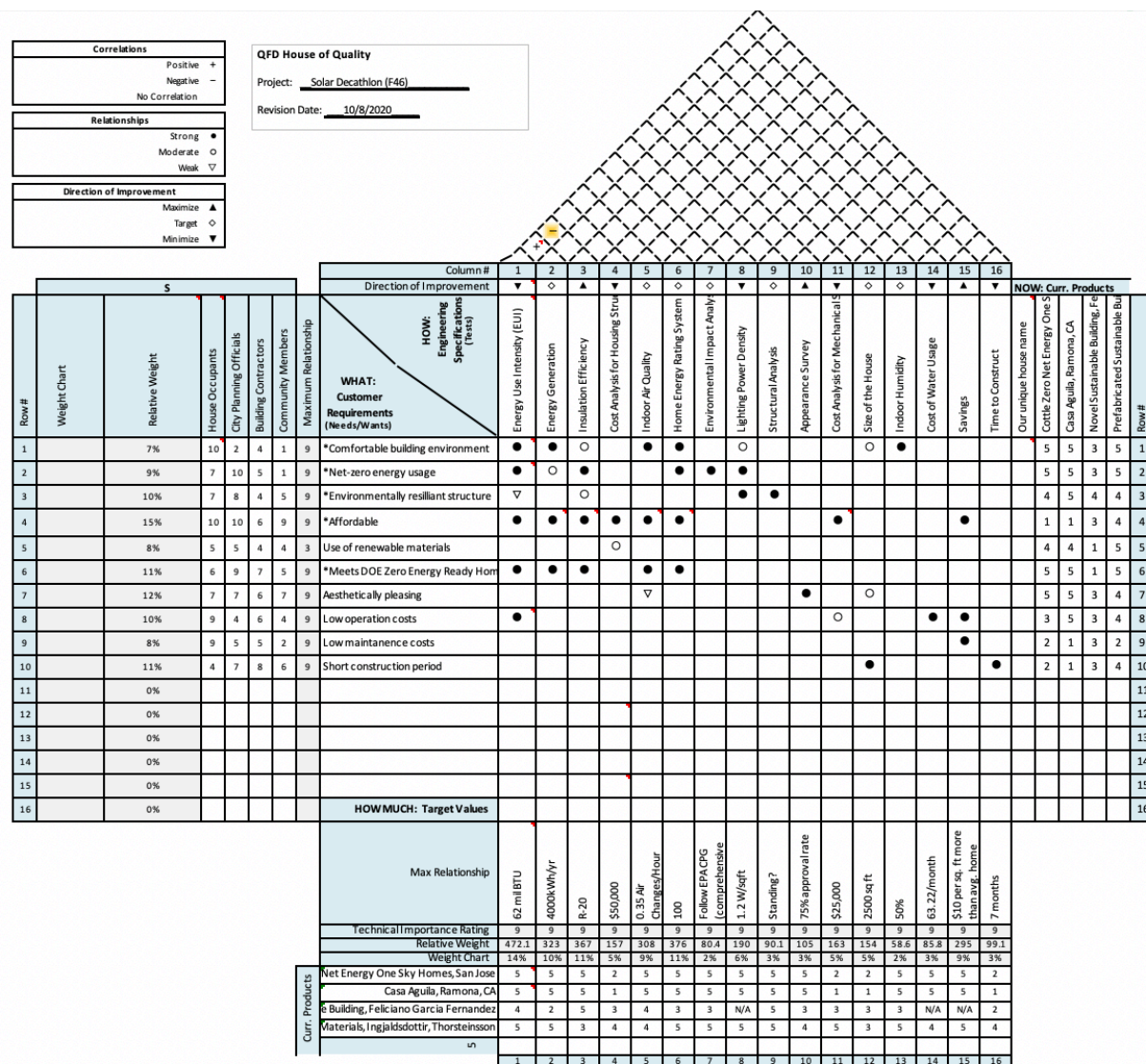
9.2 NEXT STEPS

For future sponsors and teams competing in the Solar Decathlon, we advise turning this into a club, making it an interdisciplinary senior project, or making it an HVAC concentration senior project. Although students might be less invested in a club than a senior project, this would eliminate the need to turn in other documents and deliverables while trying to complete the very daunting design portfolio. This would also set the team up for competing the Build Challenge rather than just the Design Challenge. It would create a continuity of information and knowledge within the club rather than having students learn the software, construction materials, and net-zero design elements, only to graduate. We found it difficult to line up this competition's deliverables with the traditional Mechanical Engineering senior project timeline and deliverables. Future sponsors should recruit students early from architecture, mechanical engineering, civil engineering, landscape architecture, and construction management. There should also be more structure set up for delegation and deliverables, as this is a very comprehensive competition.

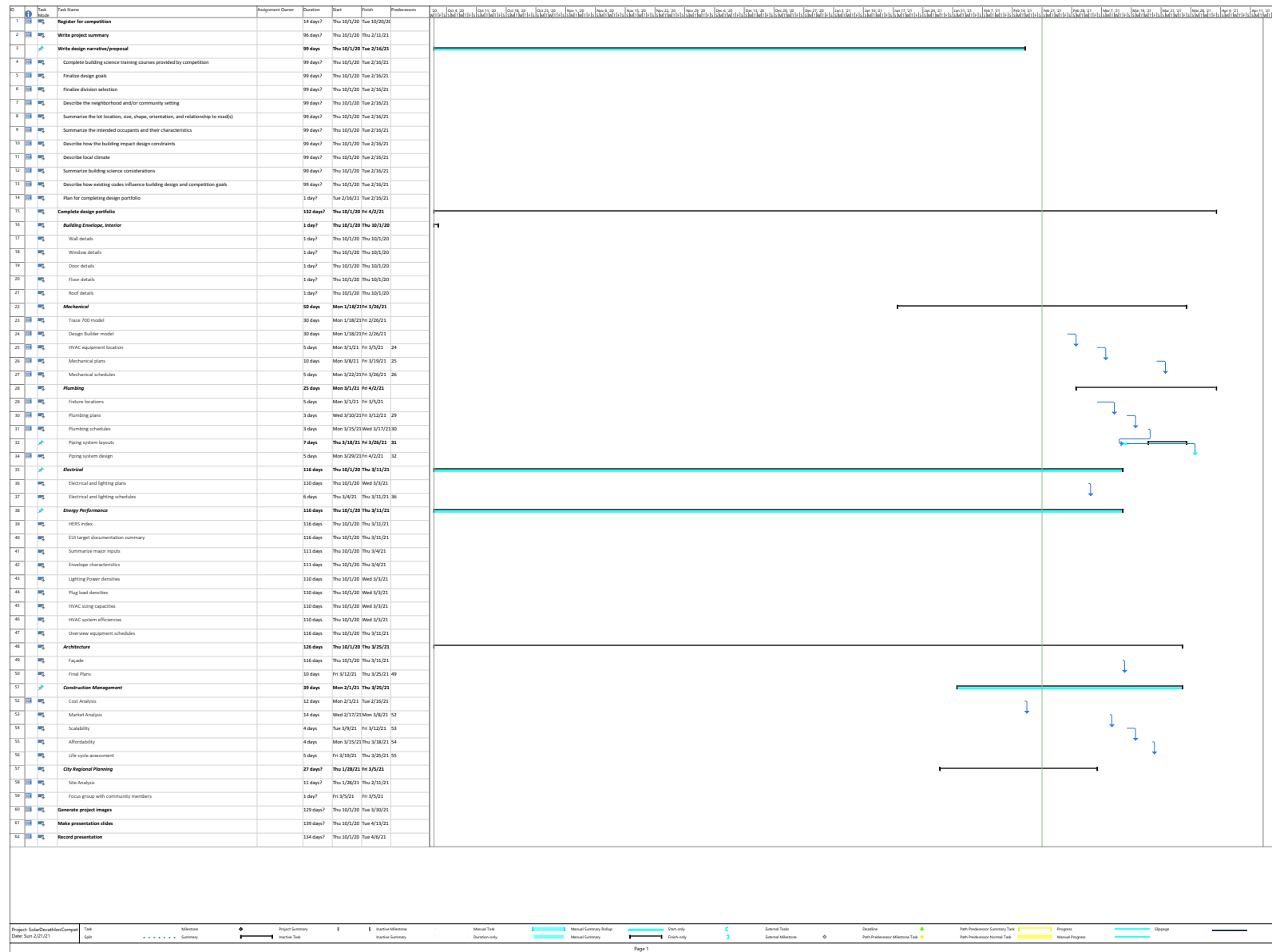
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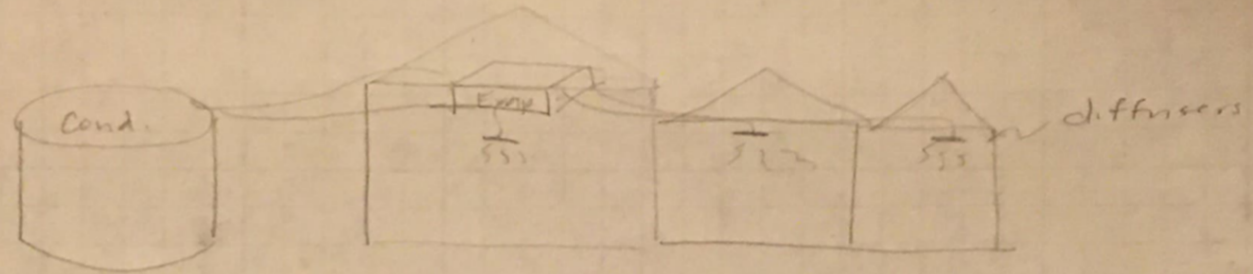
APPENDIX B: GANTT CHART



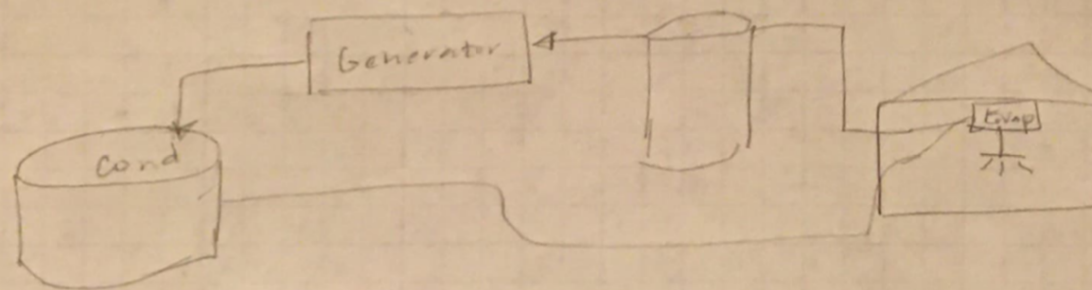
APPENDIX C: PUGH MATRIX-HVAC

Criteria	Datum					
	Split System	Absorption	Minisplit	Geothermal	PTAC	Water Sourced
Initial Cost	S	-	-	-	+	-
Energy Usage	S	-	+	+	-	+
Size	S	-	+	-	+	-
Ease of Install.	S	-	S	-	+	-
Environ. Friendly	S	+	+	+	-	S
Aesthetic	S	-	-	+	-	-
Operating Cost	S	+	+	+	-	+
Mainten	S	-	S	-	S	S
Total	0	+	2	0	-1	-2
Rank	2	5	1	2	3	4

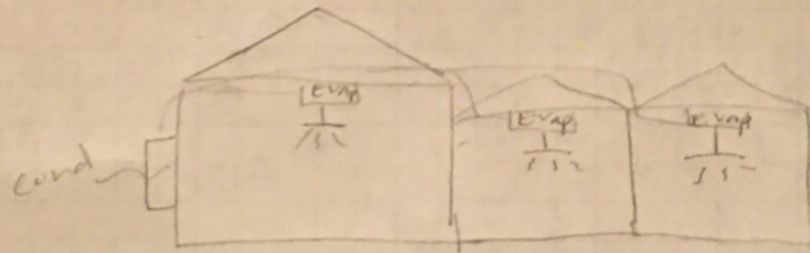
Split System:



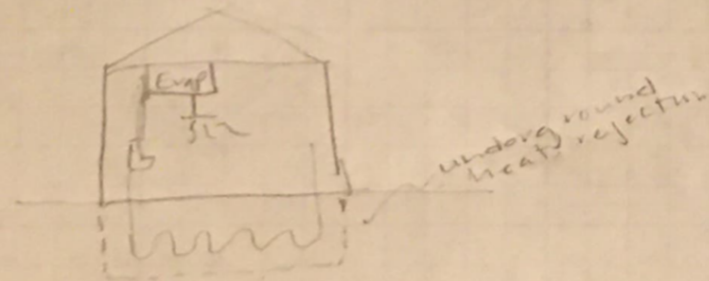
Absorption



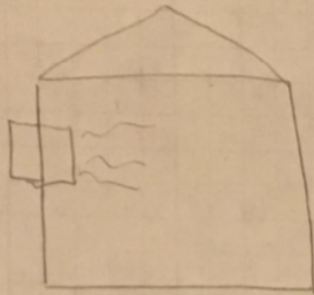
Minisplit



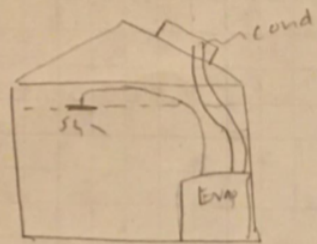
Geothermal



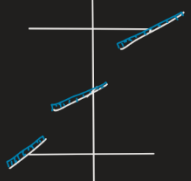
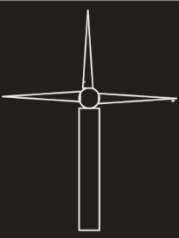
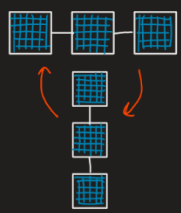
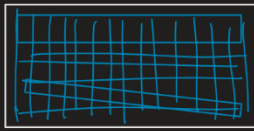

PTAC





Water Source



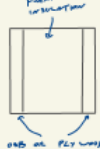
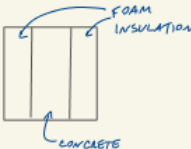




APPENDIX D: PUGH MATRIX-POWER SYSTEM

CRITERIA				 FIXED, LARGE	 KINETIC ENERGY
AFFORDABLE	D	—	S	S	—
LOW MAINTENANCE COSTS	A	—	S	S	—
AESTHETICALLY PLEASING	T	+	S	—	+
SHORT CONSTRUCTION PERIOD	U	—	S	+	+
RESILIENT STRUCTURE	M	—	S	+	—
SPACE SAVING	!	—	—	—	—
TOTALS		-4	-1	0	-2
RANK	1	5	3	2	4

APPENDIX E: STRUCTURAL/WINDOWS

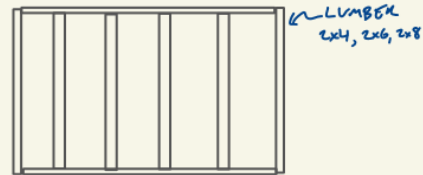
CONCEPT:						ASHLEY KIM F46
	①  ANGLED FRAME	②  ADJUSTABLE SHADING	③  ADJUSTABLE SOLAR PANEL	④  MOVABLE PARTITION	⑤  MULTIPLE WINDOW PAGES	
Comfortable building environment	S	+	+	+	+	
Net-zero energy usage	S	-	S	-	+	
Environmentally resilient structure	S	+	-	-	+	
Affordable	S	+	S	S	S	
Use of renewable materials	S	-	-	S	-	
Meets DOE Zero Energy Ready Home	S	-	+	-	+	
Aesthetically pleasing	S	S	-	-	+	
Low operation costs	S	+	-	S	-	
Low maintenance	S	+	-	S	+	
Short construction period	S	+	-	S	S	
TOTAL	0	3	-4	-3	4	

APPENDIX F: PUGH MATRIX-BUILDING ENVELOPE

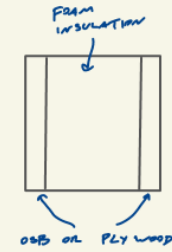
CONCEPT CRITERIA	1. TRADITIONAL CONSTRUCTION	2. SIP 	3. ICF 	4. UNDERGROUND 	5. BAMBOO 	6. SHIPPING CONTAINER 
DURABILITY		S	+	-	-	S
INSULATION FACTOR POTENTIAL		+	+	+	-	S
AIR TIGHT ENVELOPE		+	+	+	-	-
TIME TO CONSTRUCT		+	S	-	+	+
COST TO BUILD		-	-	-	+	+
TOTAL		+2	+2	-1	-1	+1

IDEAS

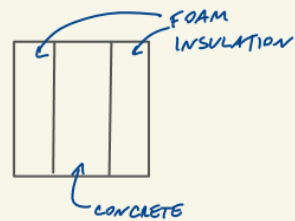
1. TRADITIONAL FRAMING



2. SIP (STRUCTURALLY INSULATED PANEL)



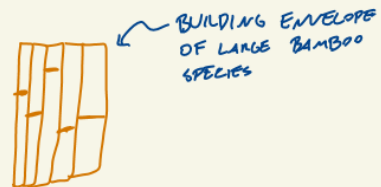
3. ICF (INSULATED CONCRETE FORM)



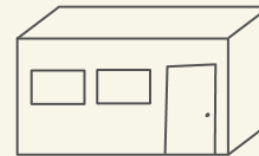
4. UNDER GROUND / GROUND INSULATED



5. BAMBOO FRAMING



6. SHIPPING CONTAINERS



APPENDIX G: GENERAL HOUSING IDEATION SESSION

10/15 IDEATION - GENERAL IDEAS

IDEA 1

HAVE A COVER

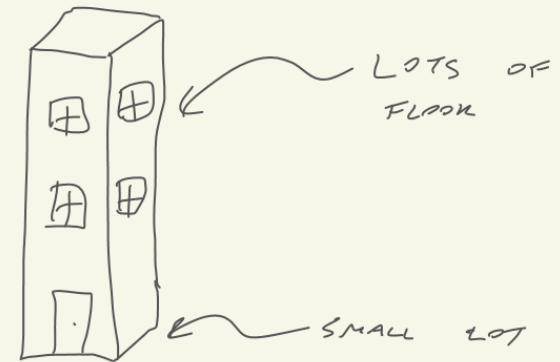


IDEA 2

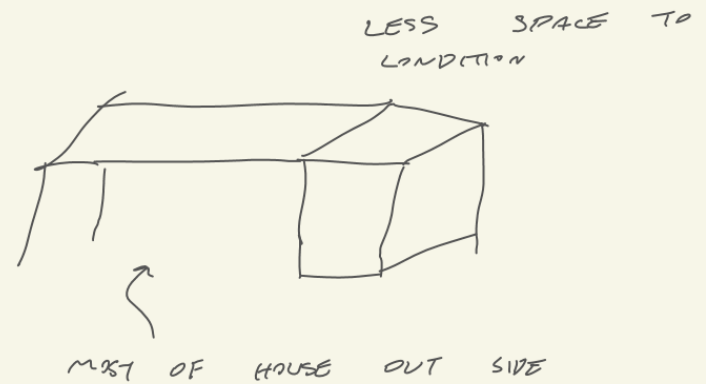
HOBBIT HOUSE



IDEA 3

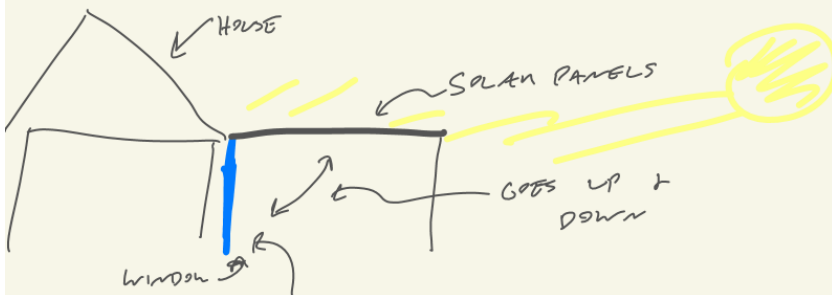


IDEA 4



LIGHTING FUNCTION

1.



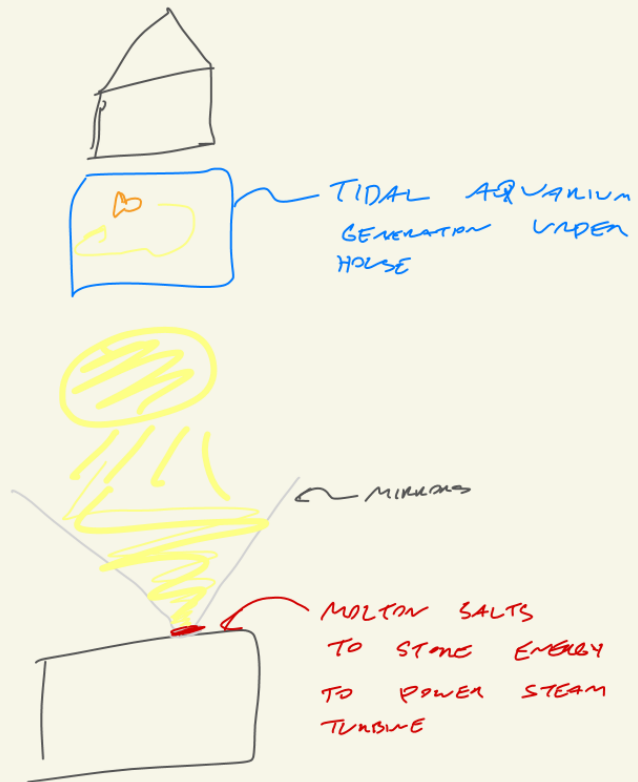
EXTRA WINDOW INSULATION
IN COLD TIMES

SOLAR POWERED LIGHTS
↑ AMBIENT
OPAQUE WINDOWS

PATIO AREA SOLAR PANEL WINGS
COME DOWN TO PROVIDE EXTRA
SHADE / INCLOSE PATIO AREA

ENERGY GENERATION

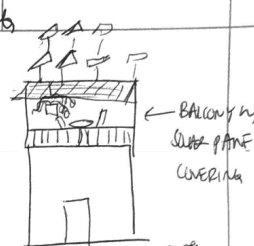
- SOLAR
- WIND
- SEISMIC ENERGY (NAVE)
- GEOTHERMAL
- SOLAR THERMAL
- TINY NUCLEAR POWER GENERATOR
- MIRRORS ON ROOF TO



APPENDIX H: BRAIN STORM

NET ZERO HOUSING

SOLAR PANELS



← BALCONY w/ SOLAR PANEL COVERING

← RECONFIGURING SOLAR PANELS

← FIXED

USE TRASH FOR BUILDING MATERIALS
→ INSULATION
→ SUPPORT STRUCTURE

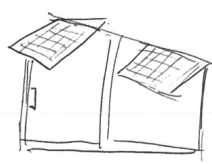
USE WHAT ALREADY EXISTENT

EXERCISE BIKE TO WASH CLOTHES

LIGHTING

MAKE HOUSE WEIRDER SHAPES/ANGLES TO GET MOST AMOUNT OF LIGHT

SOLAR SPACED SOLAR PANELS TO PROVIDE PATIO SHADING BUT STILL ALLOW LIGHT THROUGH



WALKWAY SOLAR PANEL LIGHTS TO PROVIDE AMBIENT LIGHTING IN HOUSE

SKYLIGHTS THAT CAN BECOME CLEAR/TRANSPARENT

SWIVEL WINDOWS
GLASS BOTTLES IN WALLS TO PROVIDE LIGHT

WINDOWS THAT CAN BE CLEAR OR OPAQUE DEPENDING ON WEATHER

ENERGY GENERATION

BIKE POWER GENERATION

PV / THERMAL SOLAR POWER SYSTEMS

WIND TURBINES

SEISMIC POWER?

GEOTHERMAL POWER

HYDROELECTRIC

FOLDABLE SOLAR PANELS OFF ROOF

USE PAPER CARBON MATERIAL FOR ENERGY STORAGE

BATTERIES

SOLAR WATER HEATERS

PUMPING GREY WATER THROUGH WALLS

BATTERIES LAST RESORT

MATERIALS

BAMBOO !!!

PEW/M INSULATION

REUSE OTHER INSULATIONS

DIRT / MUD

TILES AS WALL INSULATION

TAKE BUILDING MATERIALS

GLASS BOTTLES

USING TRASH-TRASH FOR CONSTRUCTION THINGS THAT CAN'T BE RECYCLED

POLISHED DIRT FLOOR

CEMENT FLOORS, HEATING COOLING w/ WATER

CLAY

CARBON CAPTURE CONCRETE SELF HEATING

Brain Dump	
Passive House	Mechanical Systems
-orientation	-VRF, HRV
-windows (type, location, tilt)	-minimal
-insulation	-heat pump
-natural light	
	Floor plan
	-open floor plan
Energy	Material
-solar PV	-bamboo composite
-solar thermal	-dirt?
-wind	-shipping containers
	-recycled
Plumbing	Codes
	-CA Mech Code
	-LA Municipal Code
	Lighting
	-roof shape - allow more sun
	-patio w/ solar panels

APPENDIX J: JAMBOARD GROUP BRAIN DUMP SESSION

Arch=blue
 energy = orange
 mech/temp control = yellow
 sustainable strategies = green
 misc = pink

partitions	solar panel wings	compost	solar water heaters	minimalistic living	vertical/horizontal shading devices	orientation for maximum ventilation	recyclable materials for insulation	electric stove tops, no gas	sustainable landscape
use of trash somehow in insulation or construction or fuel? @ Sweden	reconfigurable solar panels	green roofs and garden spaces	mixed materials - recycled steel + wood	potential water spots for cooling during summer	skylights with manually adjustable covers	radiant heating through floor	greywater garden	flexible/multiuse furniture	promotes mental health
planters fed by greywater	solar panel field	energy from exercising to power small things in the house	affordable transitional housing for homeless people or teenagers without families	geothermal heat pump	rotating solar panels or slanted roof for optimal angle	rainwater collecting and use for bathroom	locally sourced materials	location next to potential transitional work	differences in verticality dependant on the number of occupants
operable, flexible shading devices	taking advantage of summer/winter sunlight	promote sociability	phase change material energy storage	recycled lining plumbing pipe	focus on small families	promote self reflection in what you use	patio with solar panels above for shade	modular design that can be copied to potentially create communities	ice bank system to use energy when its the cheapest during the day
tiny living/space-efficient housing	adjustable floorplan	https://www.archdaily.com/887269/contented-ores-franceschi-re-arg-uitectura-plus-dao?ad_source=search&ad_medium=search_result_projects	energy generation from movement/exercise						

APPENDIX K: JAMBOARD BRAIN WRITING



Anne

**timber
structure,
wooden
siding**

**two floors,
patio garden
for private
outdoor
spaces**

**multi-use
spaces,**

**Minimal
maintenance**

**encourage
community
engagement
with shared
spaces**

**outdoor
community
spaces and
indoor spaces**

**building up
not
necessarily
out**

**communal
gardens and
education
center**

**roof top patio
with solar
panel shade**

**use vining
plants/trees
for natural
shade**

**minimize ceiling
space for
mechanical/plumbing
to increase ceiling
height**

**Recycling/compost
built in**

Carina

Floor plan designed to get occupants out of the house and socialize with other community members

Use human energy/effort where possible

reusable materials

community

solar panels
everywhere
everywhere

socializable spaces

group activities and events

residents in charge of maintaining renewable energy?

recycled material for sidings

community garden??

solar panels that can add to building aesthetically...

open scheme

include Los Angeles culture

solar panel integrated cladding

home-y feeling

more communal living is emphasized

independence and dependence encouraged in the community

clean and chic

Angelee

**recycled
wood
design
scheme**

**village
style
living**

**vegetable
roof
garden**

**rehabilitation
and
community
integration**

**mixed used
spaces (pop
up shops??)**

**kitchen island
as a
desk/office
space**

**stacked
modules**

**integrated
plumbing
and
irrigation**

**resource
center**

**community
garden**

**kinetic
energy
use**

**efficient space
layout to
minimize
plumbing
piping**

**easy access/location
to resources for
particular group**

**Solar
shade**

**make
trash
fabulous**

**trash to make
energyyyy???**

**community
compost
garden**

**flexible
furniture**

Khanh

reconfigurable
furniture

space
saving
furniture

features built
into the walls
like tables,
storage, etc

rooms whose
use can be
changed from
public to
private using
partitions

Modular
design that
can be easily
replicated to
create small
community

modular
rooms

sliding
doors for
flexible
spaces

hidden
compartment
closets

partitions
that
separate
rooms

look at tiny
home +
apartment
precedents

beds that
go into
the wall

Emma



**solar
panel
patio**

**solar
panel
shade**

**position
public spaces
in areas with
most daylight**

**Franceschi
Container
Houses / Re
Arquitectura +
DAO**

**Bamboo
composite**

**patio area
incorporated
into the home**

**using bamboo
corrugated
walls**

**mix between
bamboo
structure and
wood exterior**

**bamboo for
light
aesthetics, fid
local bamboo
woodshops?**

**bamboo
shading
devices**

**bamboo
design to
minimize
destruction
during
earthquakes**

**glazed
windows for
west
orientation**

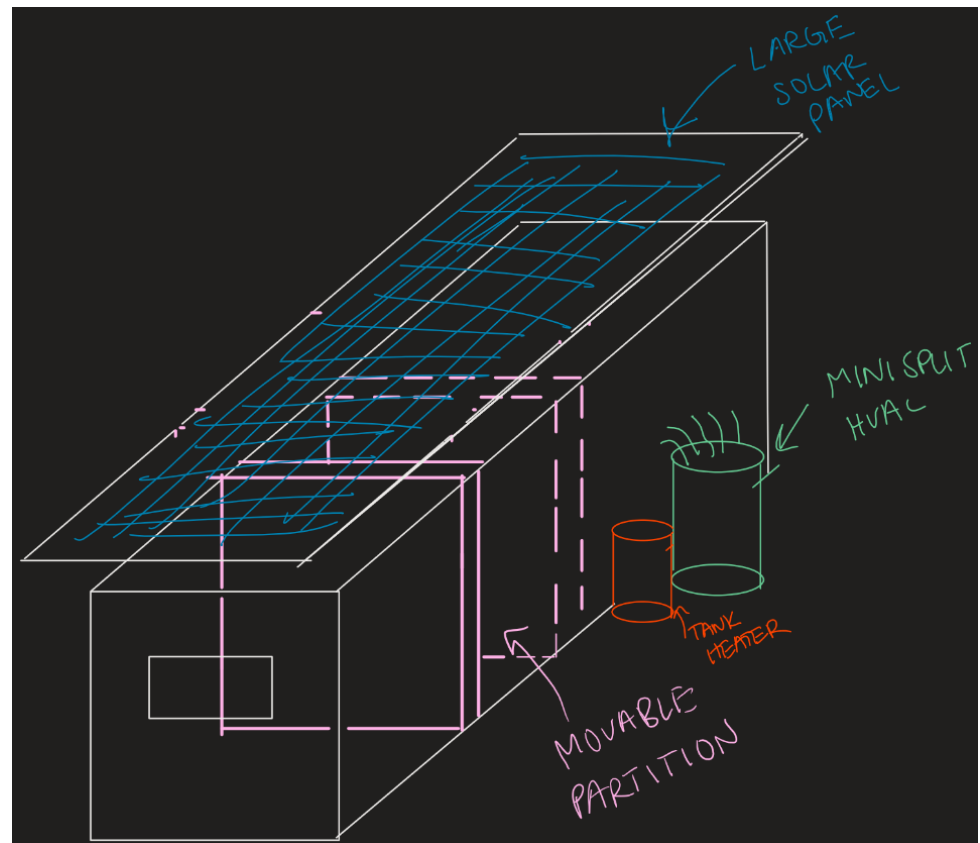
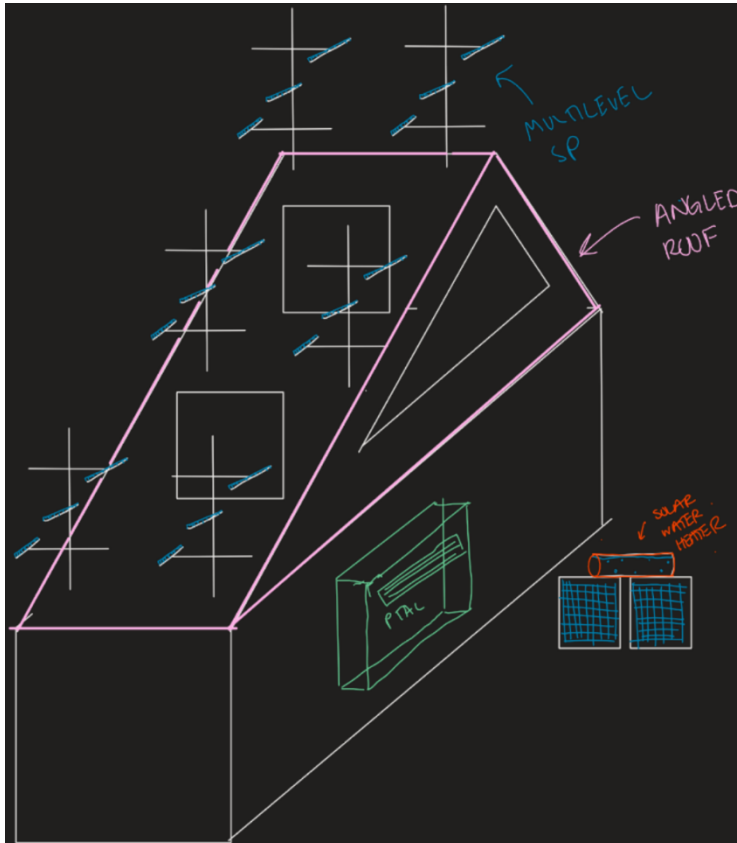
**bamboo hemp
storage
containers**

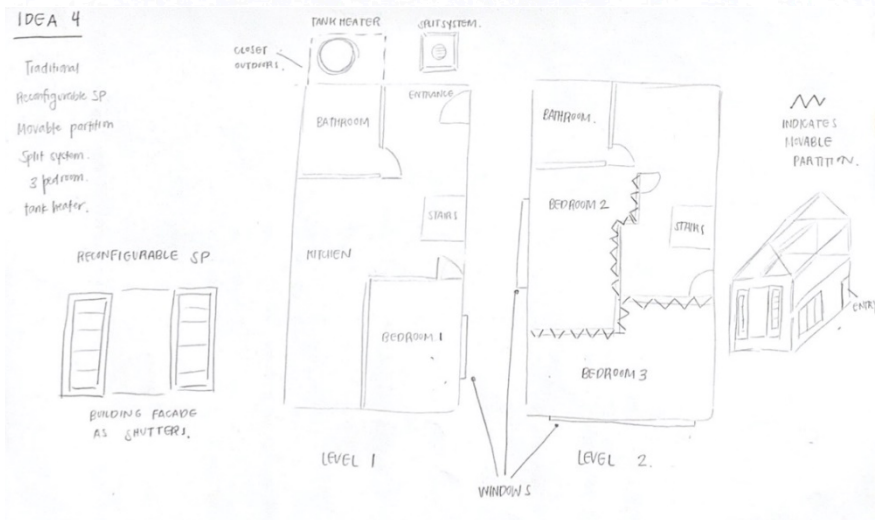
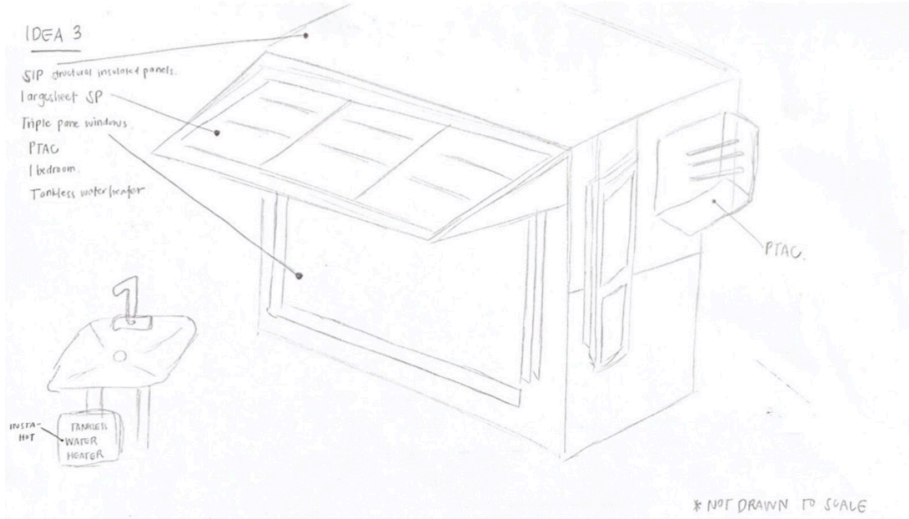
APPENDIX L: WEIGHTED DECISION MATRIX

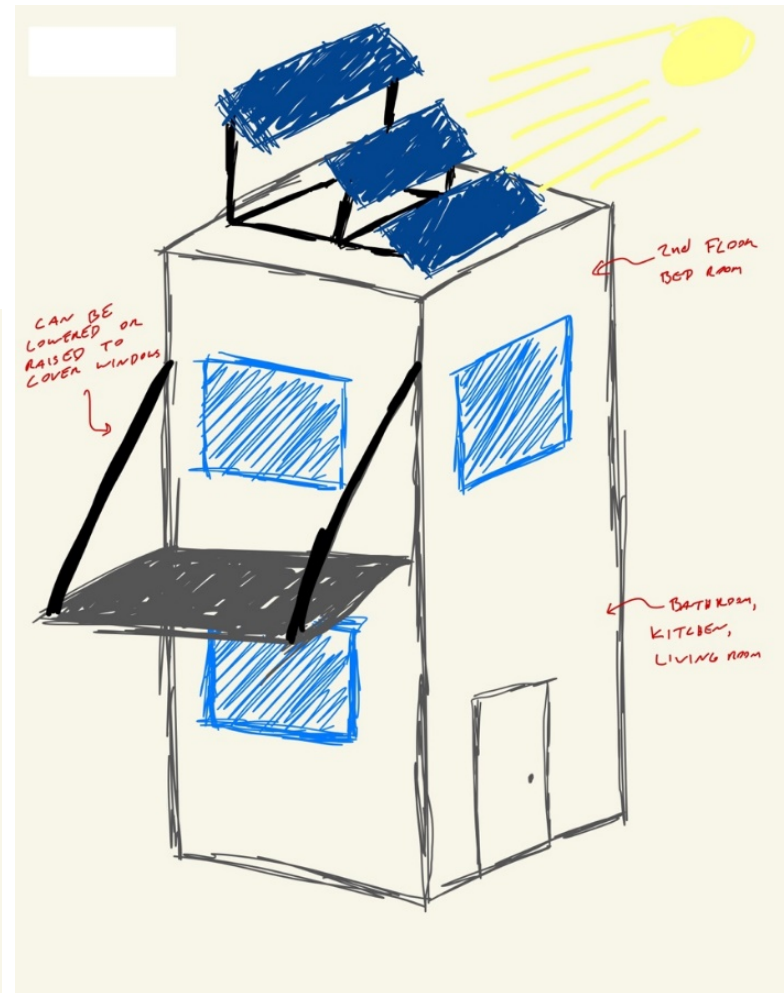
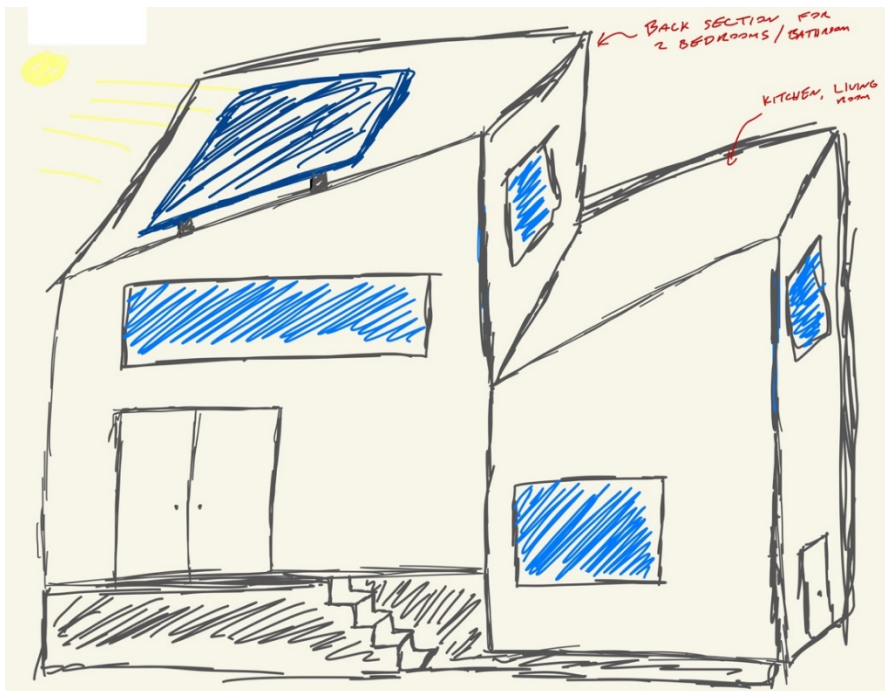
Specifications	Weight	1		2		3		4	
		Score	Total	Score	Total	Score	Total	Score	Total
Net-zero energy usage	5	4	20	4	20	5	25	4	20
Building size: 300–2,500 ft ² (28–232 m ²)	5	5	25	5	25	5	25	2	10
Lot size: up to 5,000 ft ² (465 m ²)	5	5	25	5	25	5	25	2	10
Meets or exceeds the DOE Zero Energy Ready Home National Program Requirements (Rev. 07)	5	5	25	5	25	4	20	4	20
Meets or exceeds the requirements set out in the California residential net-zero	5								
Durable structure	4	4	20	4	20	4	20	4	20
Affordable	4	2	8	2	8	4	16	3	12
Constructed using sustainable materials	4	4	16	4	16	3	12	4	16
Aesthetically pleasing	3	3	9	3	9	3	9	2	6
Low initial cost	4	3	12	3	12	4	16	3	12
Low operating cost	4	3	12	4	16	3	12	4	16
Low maintenance cost	2	4	8	4	8	3	6	4	8
Short construction period	3	3	9	3	9	5	15	4	12
Comfortable building environment	1	5	5	5	5	3	3	2	2
SUM TOTAL:	4	4	16	4	16	4	16	3	12
			210		214		220		176

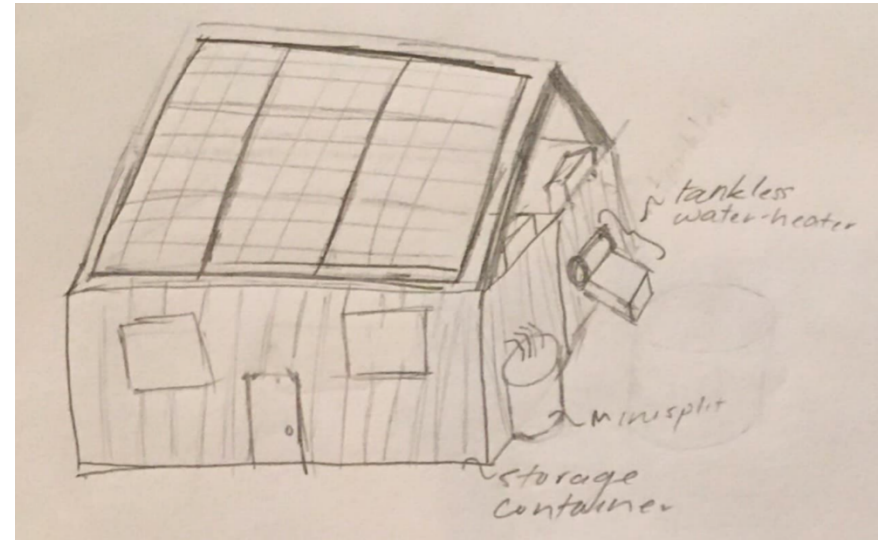
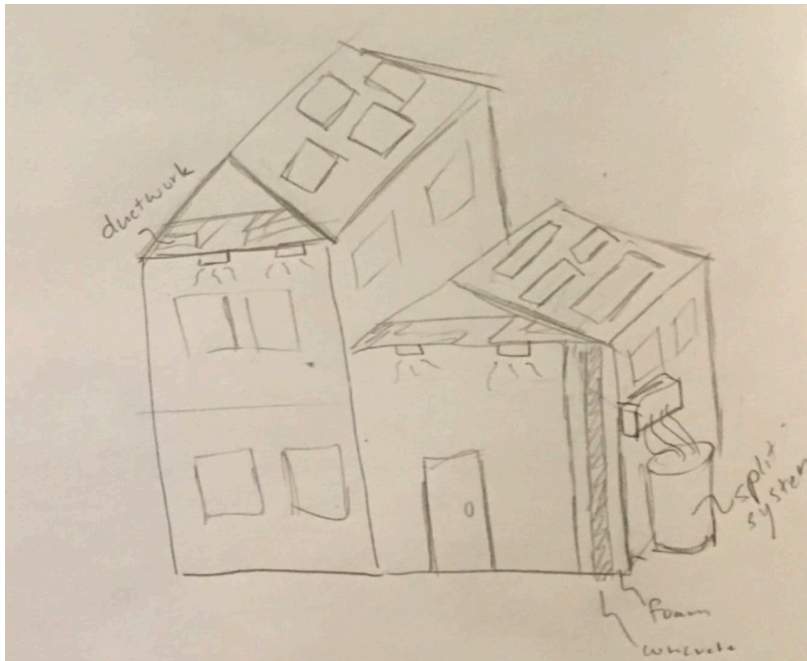
Specifications	Weight	5		6		7		8	
		Score	Total	Score	Total	Score	Total	Score	Total
Net-zero energy usage	5	5	25	5	25	3	15	5	25
Building size: 300–2,500 ft ² (28–232 m ²)	5	4	20	5	25	5	25	3	15
Lot size: up to 5,000 ft ² (465 m ²)	5	4	20	4	20	4	20	3	15
Meets or exceeds the DOE Zero Energy Ready Home National Program Requirements (Rev. 07)	5	5	25	4	20	4	20	4	20
Meets or exceeds the requirements set out in the California residential net-zero	5								
Durable structure	5	5	25	3	15	3	15	4	20
Affordable	4	5	20	3	12	4	16	5	20
Constructed using sustainable materials	4	2	8	3	12	4	16	3	12
Aesthetically pleasing	3	2	6	4	12	4	12	3	9
Low initial cost	4	4	16	4	16	2	8	4	16
Low operating cost	4	3	12	5	20	4	16	3	12
Low maintenance cost	2	5	10	3	6	3	6	5	10
Short construction period	3	5	15	4	12	4	12	3	9
Comfortable building environment	1	2	2	1	1	5	5	2	2
SUM TOTAL:	4	5	20	3	12	2	8	5	20
			224		208		194		205

APPENDIX M: WEIGHTED DECISION MATRIX CONCEPT DESIGN SKETCHES





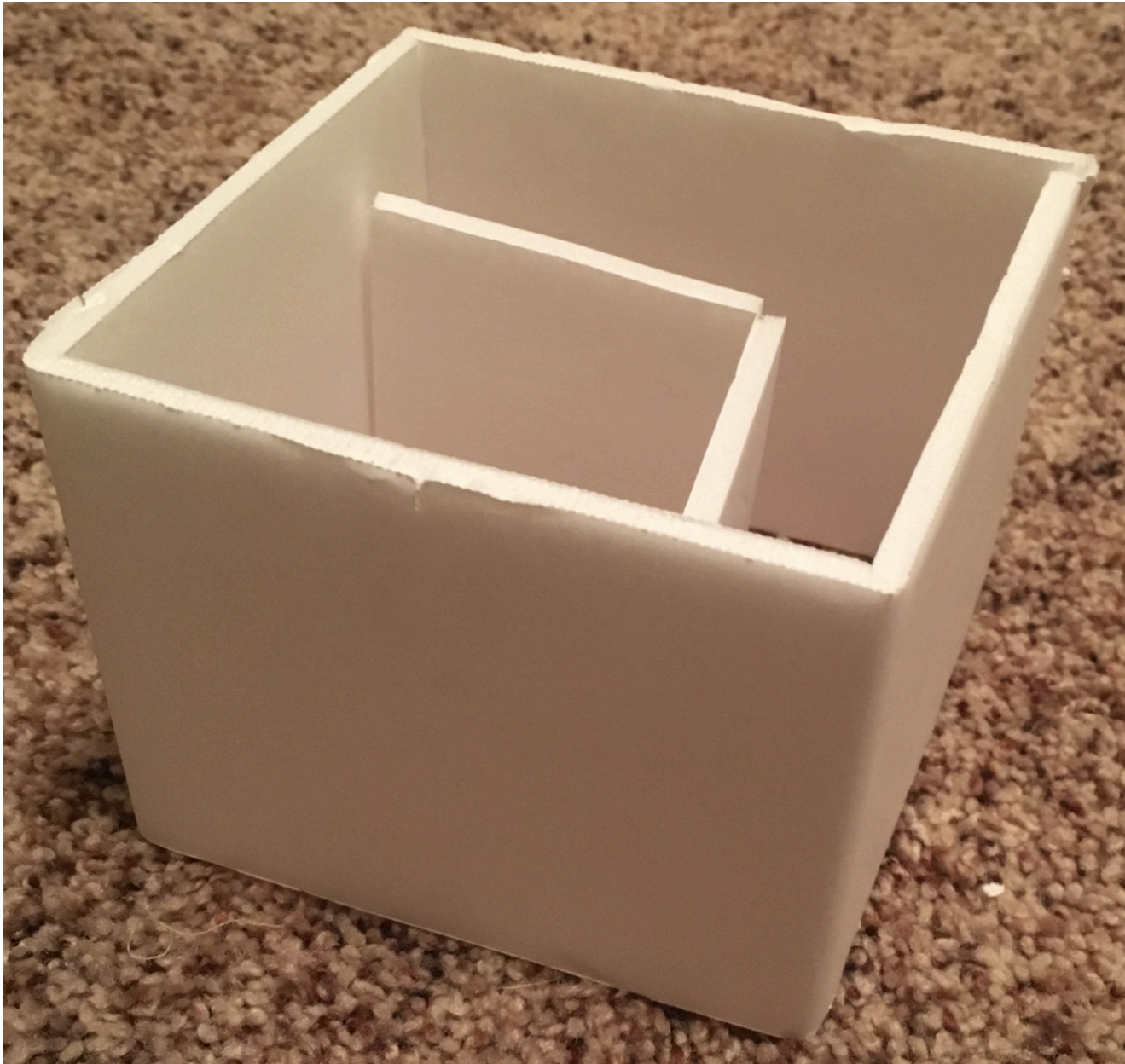


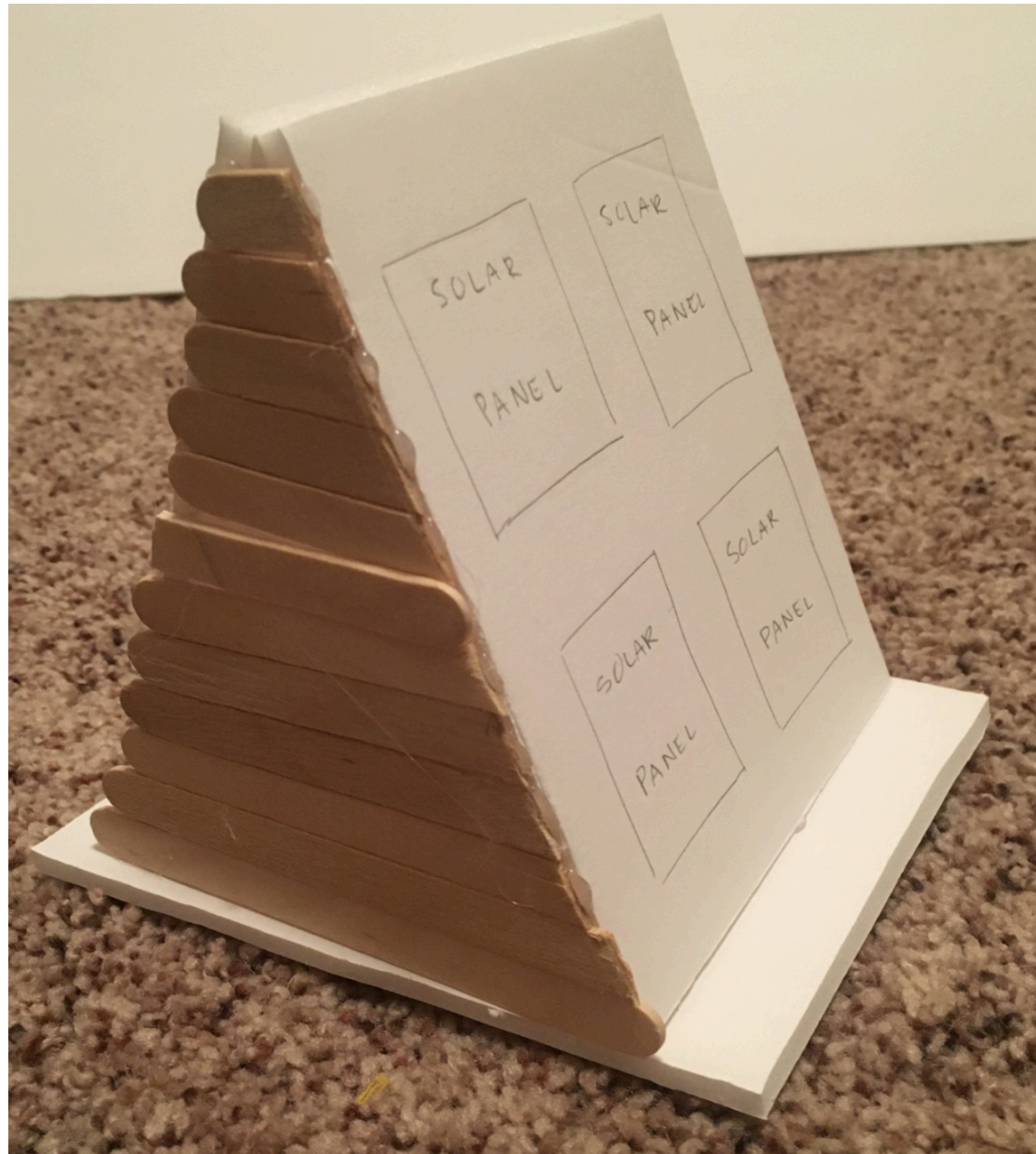


APPENDIX N: FUNCTION PROTOTYPES











APPENDIX O: SOLAR PANEL CALCULATIONS

SOLAR PANEL CALCS	
<p>ACCORDING TO DATA LA COUNTY GOV, ELECTRICITY CONSUMPTION PER CAPITA IS:</p> $E = \frac{19,468.9 \frac{\text{GWh}}{\text{year}}}{10,231,271} \times \frac{10^6 \text{ kWh}}{\text{GWh}} = 1902.9 \frac{\text{kWh}}{\text{year}} \times \frac{\text{year}}{365 \text{ days}} = 5.2 \frac{\text{kWh}}{\text{day}}$	
<p>OUR ATTACHED HOUSING IS COMPOSED OF:</p> <ul style="list-style-type: none"> 2 2-BEDROOM UNITS - 4 PEOPLE / UNIT 4 1-BEDROOM UNITS - 2 PEOPLE / UNIT 2 STUDIO UNITS - 2 PEOPLE / UNIT 	
<p>TOTAL PEOPLE : $2(4) + 4(2) + 2(2) = 20$ RESIDENTS</p>	
<p>POWER REQUIRED: $P_{\text{REQ}} = \frac{5.2 \text{ kWh}}{\text{day}} \times 20 = \frac{104 \text{ kWh}}{\text{day}}$</p>	
<p>USING DATA FROM CHEAPEST SOLAR PANEL IN MARKET</p>	
<p>RENE SOLA - JCL2SSM-24/B6:</p>	
<p>AREA: $1640 \text{ mm} \times 992 \text{ mm} \times \left(\frac{\text{m}}{1000 \text{ mm}}\right)^2 = 1.627 \text{ m}^2$</p>	
<p>BASED ON LOCAL SOLAR IRRADIANCE (FROM NREL), THE WATS AREA PRODUCES</p>	
<p>$G = 7.0 \text{ kWh} / \text{m}^2 / \text{day}$</p>	
<p>FOR 1 RENE SOLA SOLAR PANEL, IT RECEIVES THE FOLLOWING IRRADIATION</p>	
<p>$P_{\text{GEN}} = \frac{7.0 \text{ kWh}}{\text{m}^2 \text{ day}} \times 1.627 \text{ m}^2 = 11.39 \frac{\text{kWh}}{\text{day}}$</p>	
<p>TAKING INTO ACCOUNT THE EFFICIENCY OF THE PANEL (15.7%) AND THE DEGRADATION OF THE PANEL OVER ITS 25 YEAR LIFE (80%), WE CAN FIND THE POWER GENERATED USING A VERY CONSERVATIVE ESTIMATE AFTER 25 YEARS.</p>	
<p>$P_{\text{GEN}} = 11.39 \frac{\text{kWh}}{\text{day}} \times .157 \times .80 = \frac{1.43 \text{ kWh}}{\text{day}}$</p>	
<p>NUMBER OF PANELS NEEDED: $N = \frac{P_{\text{REQ.}}}{P_{\text{GEN.}}} = \frac{104}{1.43}$</p>	
<p>$N = 72.7 = 73 \text{ PANELS}$</p>	

APPENDIX P: DESIGN HAZARD CHECKLIST

DESIGN HAZARD CHECKLIST

Team: F-46 SOLAR DECATHLON Faculty Coach: ELBHANOUR

Y	N	
<input type="checkbox"/>	<input checked="" type="checkbox"/>	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	2. Can any part of the design undergo high accelerations/decelerations?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	3. Will the system have any large moving masses or large forces?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	4. Will the system produce a projectile?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	5. Would it be possible for the system to fall under gravity creating injury?
<input checked="" type="checkbox"/>	<input type="checkbox"/>	6. Will a user be exposed to overhanging weights as part of the design?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	7. Will the system have any sharp edges?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	8. Will any part of the electrical systems not be grounded?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	9. Will there be any large batteries or electrical voltage in the system above 40 V?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
<input checked="" type="checkbox"/>	<input type="checkbox"/>	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	14. Can the system generate high levels of noise?
<input checked="" type="checkbox"/>	<input type="checkbox"/>	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
<input checked="" type="checkbox"/>	<input type="checkbox"/>	16. Is it possible for the system to be used in an unsafe manner?
<input checked="" type="checkbox"/>	<input type="checkbox"/>	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Description of Hazard	Planned Corrective Action
Vulnerable customer	Lighting in dark areas in and around building, elevate residential spaces above first floor
Structural, Seismic, Fire Hazards	Perform structural integrity tests, follow building codes
Refrigerant	Keep it contained in HVAC and Refrigerator
Roofs, floors, balconies as overhangs	Perform structural calculations to make sure building is safe

APPENDIX Q: INDENTED BILL OF MATERIALS

Indented Bill of Material (iBOM)

Assembly Level	Part Number	Description	Qty	Cost	Ttl Cost	Source	More Info
		Lvl0 Lvl1 Lvl2 Lvl3 Lvl4					
0		Final Building				-----	
1		Building Envelope				-----	
2		Insulation					
3		Rigid Insulation (Quantity in packs of	85	\$56.08	\$4,766.80	Amvic	AMDKIT001
3		Cellulose (Quantity in pallet of 36 ba.	267	\$455.00	\$121,485.00	GreenFiber	INS765LD
2		Structure					
3		Plaster Board	TBD		#VALUE!		
3		Studs	TBD		#VALUE!		
3		Plywood	TBD		#VALUE!		
1		HVAC					
2		Fan Coil Units	24	\$2,000.00	\$48,000.00	LG	
2		DOAS	4	\$1,500.00	\$6,000.00	LG	
2		Condensing Units	2	\$1,000.00	\$2,000.00	LG	
2		Branch Controllers	4	\$700.00	\$2,800.00	LG	
2		Pumps	12	\$100.00	\$1,200.00	LG	
2		Refrigerant Piping	720	\$20.00	\$14,400.00	Ferguson	
2		Ductwork	720	\$55.00	\$39,600.00	Carrier	
1		Solar Power System	46500	\$2.75	\$127,875.00	Qty is system wattage, cost is avg system cost per watt in LA county	
1		Plumbing					
2		Fixtures					
3		Showerheads	12	\$19.99	\$239.88	Delta	56272-15-BG
3		Toilets	12	\$144.13	\$1,729.56	Niagara	N7716
3		Faucets					
4		Kitchen Sink Faucet	12	\$133.81	\$1,605.72	Delta	440-DST
4		Bathroom Sink Faucet	12	\$39.00	\$468.00	Delta	B2511LF-PPU
4		Bathtub Faucet	12	\$19.41	\$232.92	American Std.	8888026-002
2		Piping	TBD		#VALUE!		Dependent on Arch.
1		Appliances					
2		Kitchen					
3		Refrigerator	12	\$674.00	\$8,088.00	Frigidaire	model FFHT1425VV
3		Dishwasher	12	\$429.00	\$5,148.00	Whirlpool	model WDF330PAHB
3		Electric Range	12	\$848.00	\$10,176.00	Samsung	model NE63T8111SS
3		Microwave	12	\$50.94	\$611.28	RCA	model RMW733
2		Laundry Room					
3		Washer	6	\$798.00	\$4,788.00	Samsung	model WF45R6300AV
3		Dryer	6	\$798.00	\$4,788.00	Samsung	model DVE45R6300V
Total Parts			48338	(Not Accurate)			

APPENDIX R: DESIGN BUILDER PRELIMINARY SIMULATION RESULTS

Description	Cooling Load (kBTU/hr)
Baseline – all zones, no window shading, 30% glazing, triple pane windows	590
Without community center, storage, or parking	525
With window shading	483
18% Glazing	470
Double Pane	470
Taking out stairwells	406.87

APPENDIX S: DESIGN VERIFICATION REPORT

DVP&R - Design Verification Plan (& Report)										
Project:	F46 Solar Decathlon			Sponsors:	Jacques Belanger and Kim Shollenberger			Edit Date: 5/19/2021		
TEST PLAN							TEST RESULTS			
Test #	Specification	Analysis Description	Acceptance Criteria	Required Software	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
							Start date	Finish date		
1	1	Simulate the heating and cooling loads for our final buidling and HVAC design	Meets power produced by PV system.	TRACE 700, Design Builder	N/A	Erich and Ashley	2/2/2021	3/10/2021	Design Builder Results: Total design heating capacity: 108 kBtu/hr, Total design cooling capacity: 174 kBtu/hr; TRACE 700: Total design heating capacity: 93 kBtu/hr, Total design cooling capacity: 134 kBtu/hr	This data uses annual design data.
2	2	Analyze solar PV system for best and worst case power production	worst case meets minimum power requirement	Helioscope	N/A	Ian	2/2/2021	3/1/2021	Annual Production w/ maximum amount of panels: 49.3 MWh Annual Production with roof-only array: 37.7MWh	These tests use TMY3 (typical meteorological year) weather data to simulate a year of production. More design options are evaluated but these are the min/max.
3	3	Test insulation combinations to determine energy lost through building envelope	Meets PHIUS insulation recommendations	Opaque	N/A	Carina	2/8/2021	3/10/2021	R-29 on second floor; R-20 on first floor; R-17 on foundation	2x6 stud framing 16" oc, cavity insulation, rigid board insulation. Second floor surpasses R-27 PHIUS recommendation; First floor does not quite meet Title 24 standard of R-21 (although we are aiming to meet Title 24 on
4	4	Model building energy to determine HERS rating	HERS index score of 0	REM/Rate	N/A	Erich	2/22/2021	3/30/2021	Without PV: HERS = 46 With PV: HERS = -3	HERS of -3 indicates we achieved net-zero status
5	5	Analyze life cycle of building to determine carbon footprint and building circularity	0.009 metric tons per sqft (LEED certification)	One Click LCA	N/A	Grace	2/22/2021	tbd	By Life-Cycle Stage: A1-A3 Materials - 84.8%, A4 Transportation - 7.6%, A5 Construction - 3.5%, C3-C4 Waste Processing - 4.1%, By Material: Doors and Windows - 38.1%, Ready-Mix - 33.5%, Insulation - 21.4%, Wood - 7%	Two methods of calculating results: life-cycle stage or material
6		Analyze cost of building to determine project budget.	\$7 million max	RSMeans	N/A	Grace	2/8/2021	3/1/2021	\$4,511,018.75	This budget is 12.5% higher than a minimally code-compliant building.
7		Determine water consumption of building.	Max 55 gallons per person per day as required by California Law (Senate Bill 686 and	Excel	N/A	Ian	2/8/2021	2/25/2021	Daily consumption per person: 53.73 gallons, yearly consumption: 784385 gallons	Based on fixture/appliance flow rates and average time of use data
8		Determine ventilation requirements of building.	Meets ASHRAE 62.1 ventilation requirements	Excel	N/A	Khanh	2/2/2021	3/10/2021	2 bed ADA: 150 cfm 2 bed non ADA: 176 cfm 1 bed ADA: 114 cfm 1 bed non ADA: 111 cfm studio 1: 55 cfm studio 2: 54 cfm community space: 441 cfm youth center: 274 cfm laundry: 216 cfm	
9		Simulate energy consumption of building to get EUI and compare to initial excel analysis	Site EUI below 36 [kBtu/ft²]	Design Builder	N/A	Erich	4/1/2021	5/11/2021	Site EUI of 17.88 [kBtu/ft²]	Done using an annual simulation of the model. The simple HVAC option was chosen because errors were arising from the detailed settings.

APPENDIX T: DFMEA

This contains our DFMEA for our theoretical design, as advised by our faculty advisor. Because we are not actually building a 12-unit apartment complex, we did not need to actually implement these recommended actions.

Product: _____ Design Failure Mode and Effects Analysis Prepared by: _____
 Team: _____ Date: _____ (orig)

System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Cause of the Failure Mode	Current Preventive Activities	Occurrence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Action Results				
												Actions Taken	Severity	Occurrence	Detection	Priority
HVAC / provide healthy indoor environment	Refrigerant leakage	Exposure to hazardous chemical	9	Pipe rupture and damage	Requiring regular maintenance of piping	2	Installation of a VFR refrigerant leak detector	2	36	Consulting with HVAC professionals	Carma - 01/25/2021		9	1	1	9
	Valve failure	Temperature and humidity unregulated	8	Improperly sized, selected, or installed	Ensuring proper valve selection following industry standard	4	Installation of a building management system to monitor performance	2	48	Consulting with HVAC professionals	Carma - 01/25/2021		8	3	1	18
	Pump failure	Temperature and humidity unregulated	8	Improperly sized, selected, or installed	Ensuring proper pump selection following industry standard	3	Installation of a building management system to monitor performance	2	36	Consulting with HVAC professionals	Rwan - 01/29/2021		8	2	1	12
HVAC / provide comfortable occupant experience	Filter blockage or fouling	Poor indoor air quality	7	Improper maintenance and being replaced on time	Requiring regular cleaning of filters	5	Installation of a building management system to monitor performance, manual inspection of filter	2	70	Consulting with HVAC professionals	Rwan - 01/29/2021		7	4	1	28
	ERV failure	Temperature and humidity unregulated	8	Improperly sized, selected, or installed	Requiring regular maintenance of ERV	3	Installation of a building management system to monitor performance	2	36	Consulting with HVAC professionals	Rwan - 01/25/2021		8	2	1	12
	Art on solar panel reduces production	Inadequate power production	2	panels not cleaned	clean often	4	visual inspection, decline in energy production	1	8							
Solar Power Generation / generate on site energy	Shading from trees or building limits production	Inadequate power production	7	Shading not taken into account during system design, trees not trimmed regularly, near by building construction	control nearby tree growth that may impact shading of panels, plan a path out of reach for shading from near nearby construction	4	visual inspection, sharp decline in energy production	1	28							
	Plumbing / provide clean water to occupants	water supply gets blocked	7	Internal build up and fouling	Perform pipe maintenance and cleaning	1	Regular visual inspection		0							
Plumbing / facilitate waste removal	traps in lavatories and wash closets	Upstream smell in lavatories	8	Improper installation, interceptor does its job	proper installation, align properly	2	smell	1	16							
Appliances / provide occupant with standard / modern style of living	hazardous material leakage	occupant exposure to toxic dust materials	4	Improper installation, install component failure	install high quality appliances	2	detectors for gas leakage	3	24							
Architectural / provide area for child care	Child care area not adequate for amount of children	parents do not have access to childcare	3	not allowing enough square footage for daycare during design	installing minimum square footage for daycare	2	regularly discussing plans with architects	4	24							
Architecture / protect residents from community threats	structural / lock and hardware, weak security	Occupants lose sense of security	8	vandalism, burglary	structural locks and hardware, fire-resistant windows, surveillance cameras, security alarms	6	surveillance cameras, security alarms, police	2	96	Reaching out to community partners, feedback from residents	Ashley - 10/4/2021		8	4	1	32
Architecture / protect residents from environmental exposure	building envelope is compromised	Occupants are in danger of falling structure	10	earthquakes, fire, unsafe construction materials	Building codes, inspections	1	building inspection	3	30	Check LA municipal codes	Ashley - 10/4/2021		10	1	2	20
Architecture / aesthetically pleasing	building appears run down or restricting	occupant has negative associations with home	2	lack of consideration of aesthetics in architectural design or integration of engineering components	regularly checking in with architecture professionals and electricians	4		3	24							

APPENDIX U: DRAWING PACKAGE

This drawing package was made with the help of the architectural team. They produced the architectural renders and floor plans, which we then drew over to make the mechanical plans. It includes the Revit plans that we submitted as part of our Verification Prototype. It also includes the cut-sheets of all materials, which a builder would need to carry out our design.

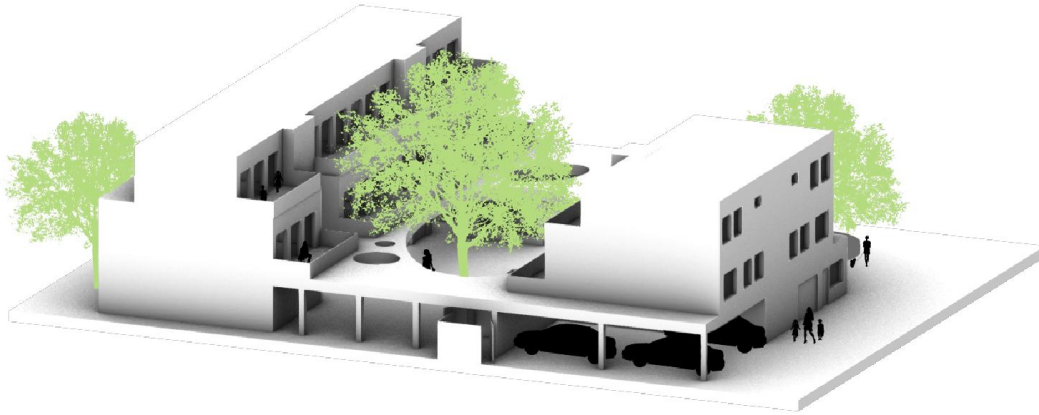


Figure U.1. Isometric Rendering from Architecture Team

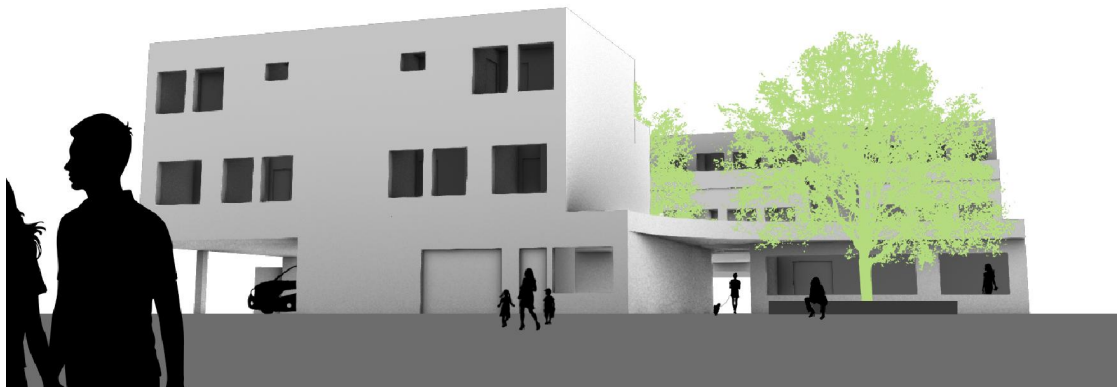


Figure U.2. Front View Rendering from Architectural

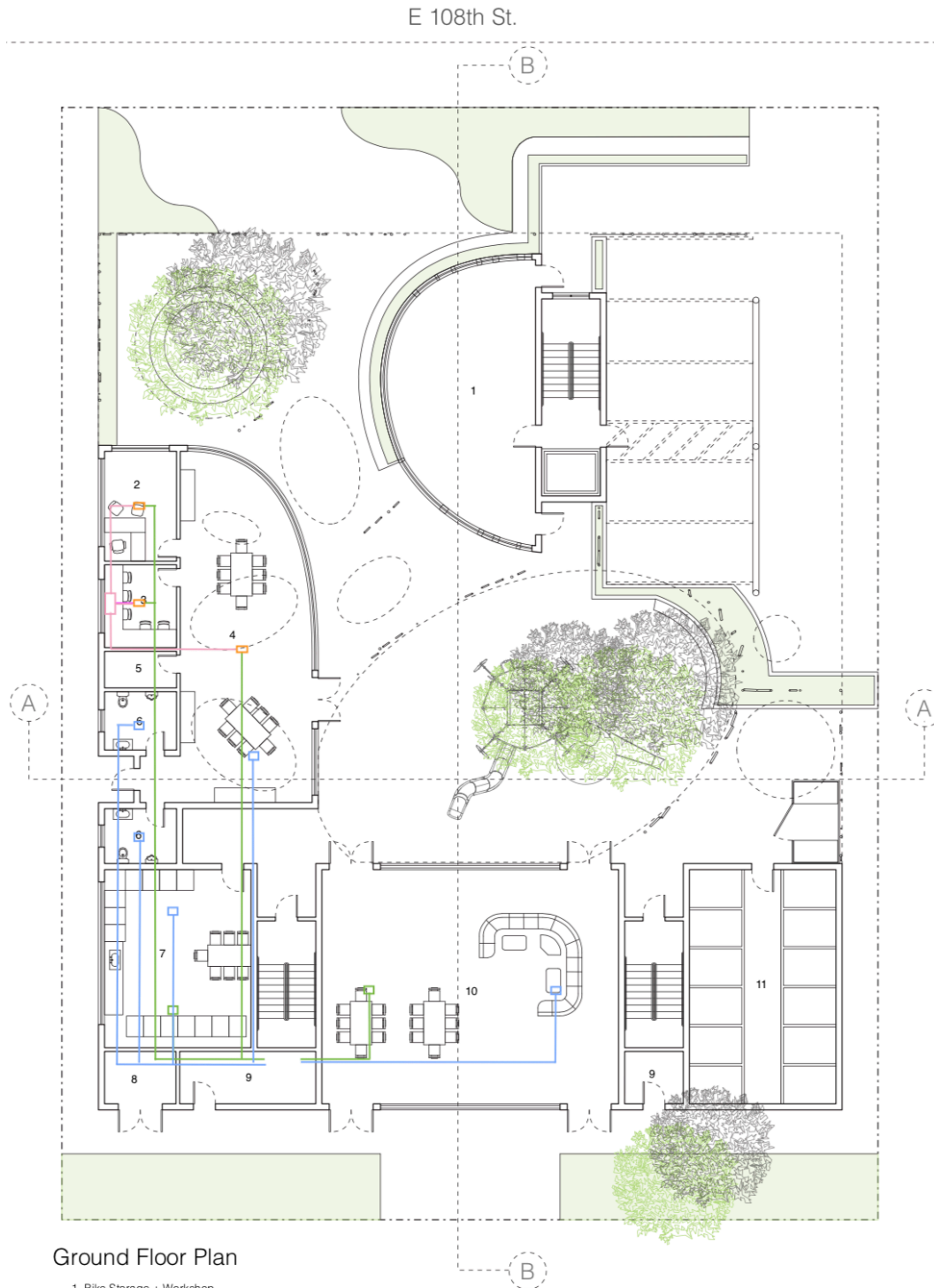


Figure U.3. First Floor Mechanical Plan

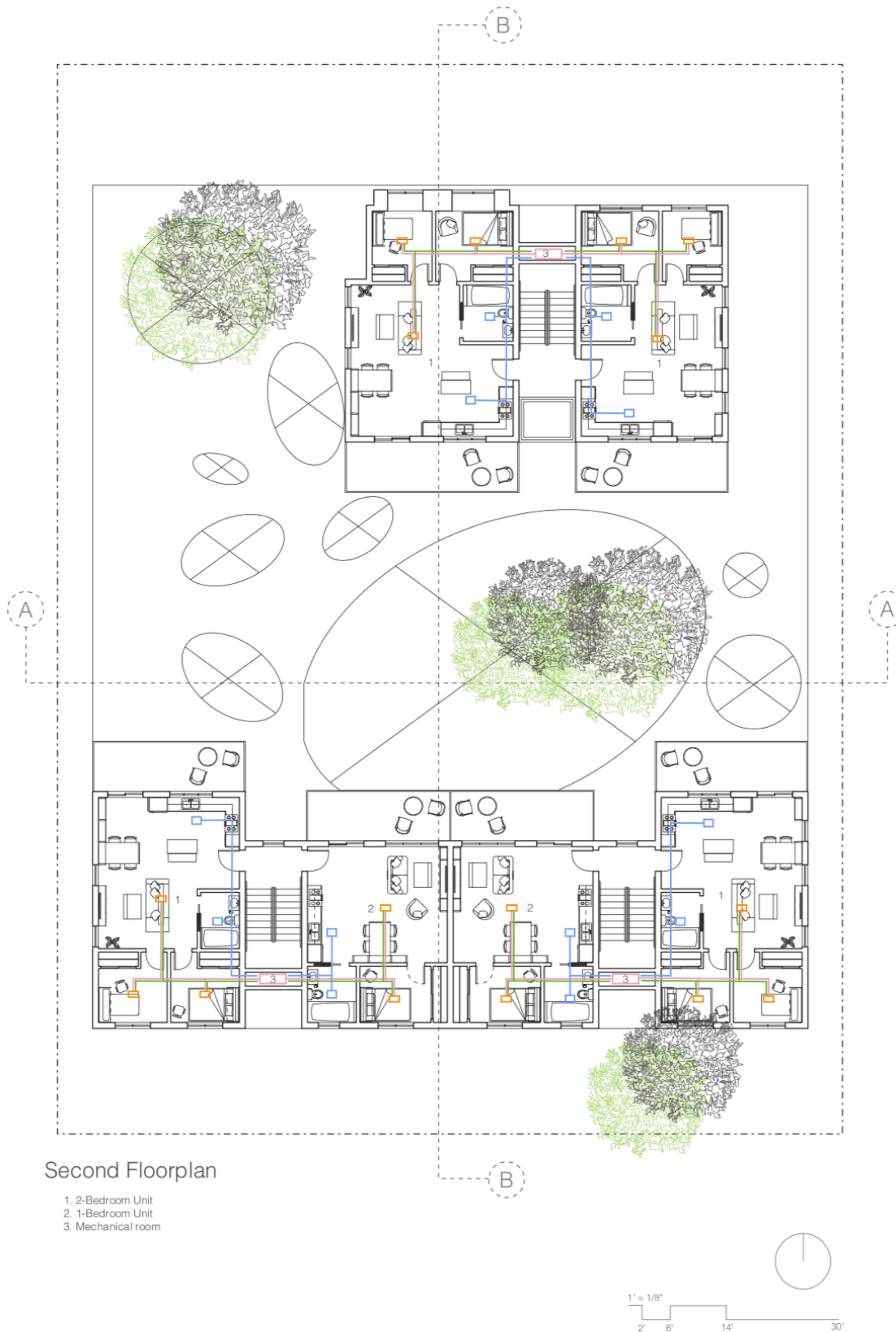


Figure U.4. Second- Floor Mechanical Plan

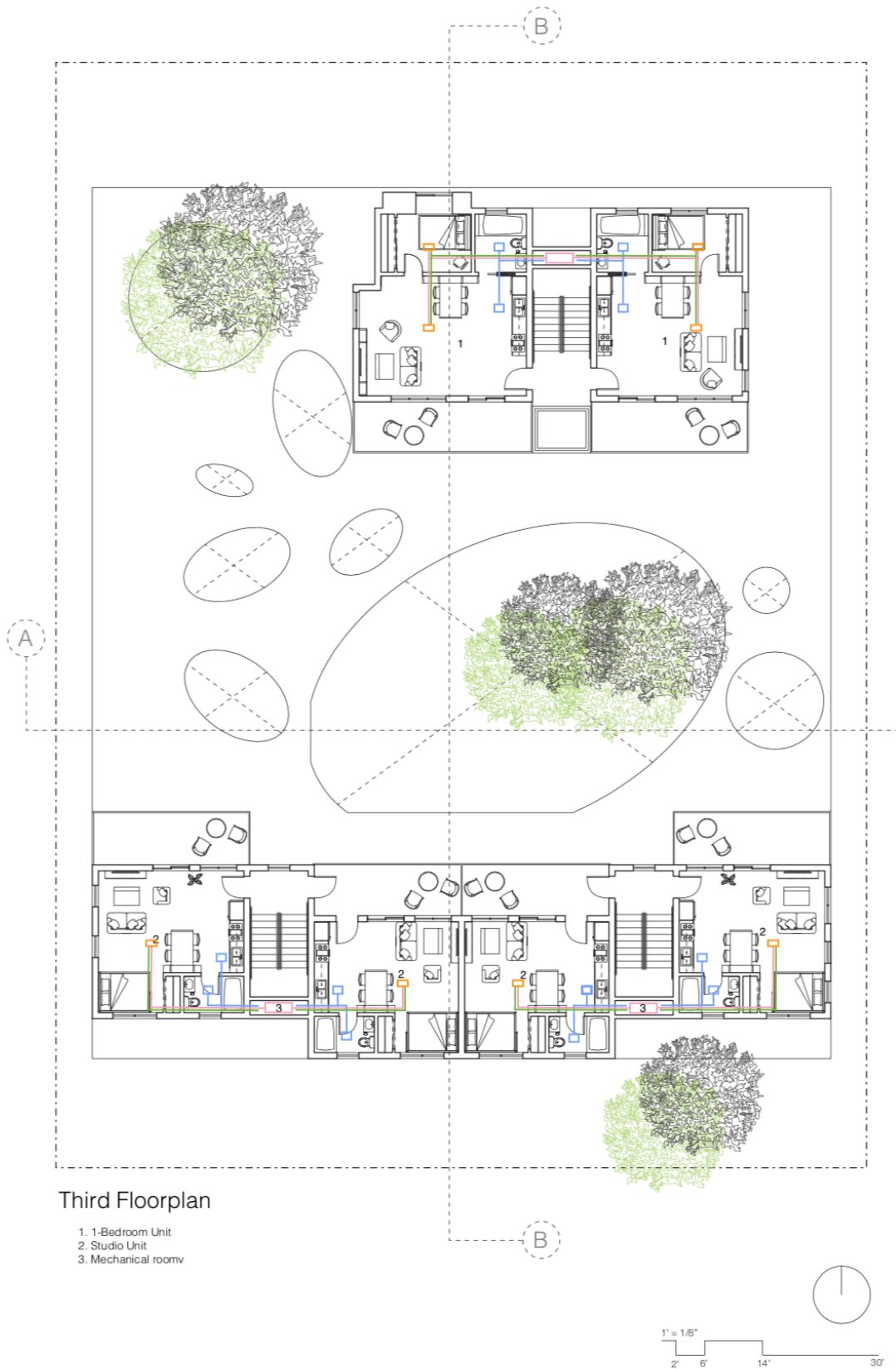
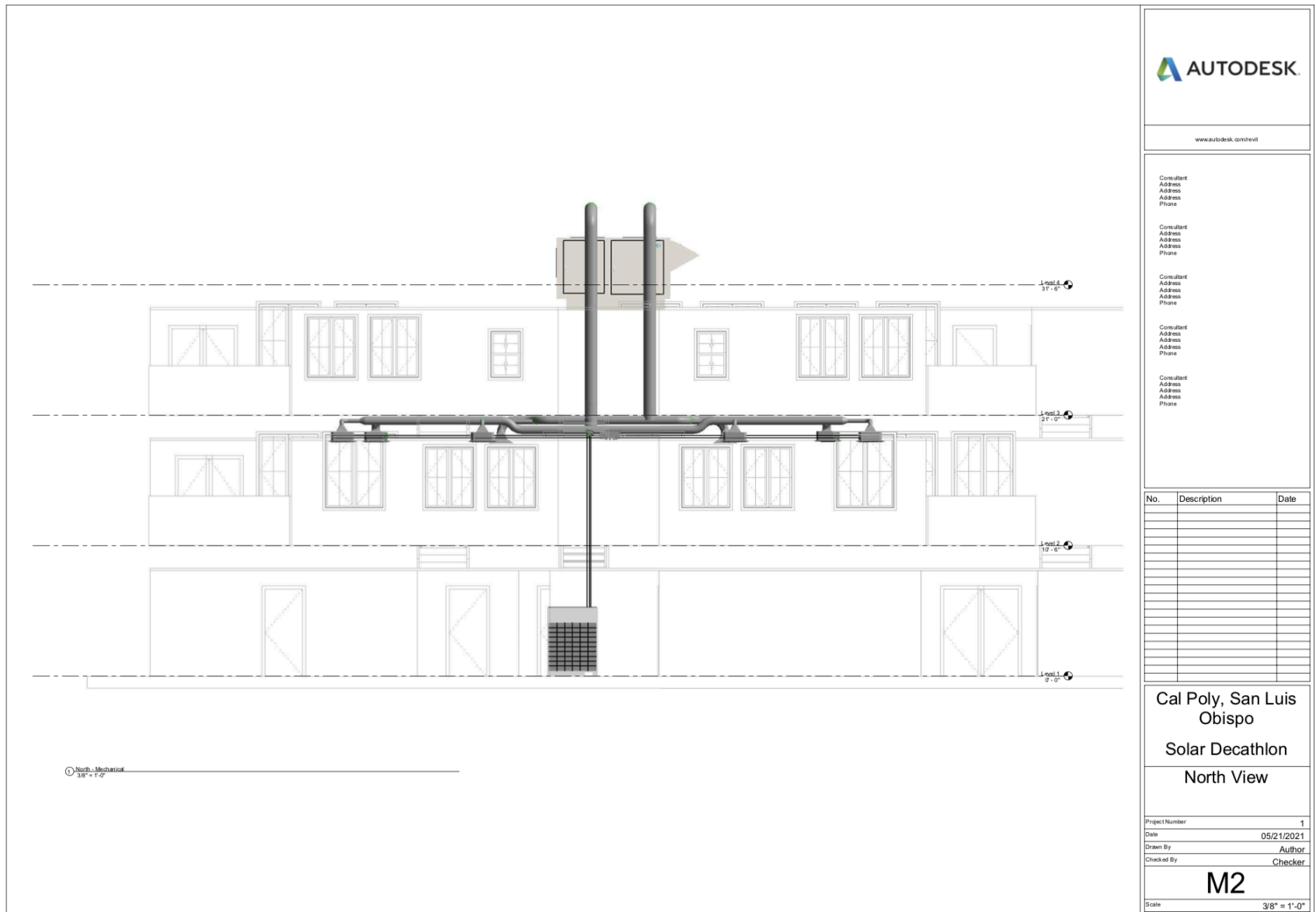


Figure U.5. Third-Floor Mechanical Plan





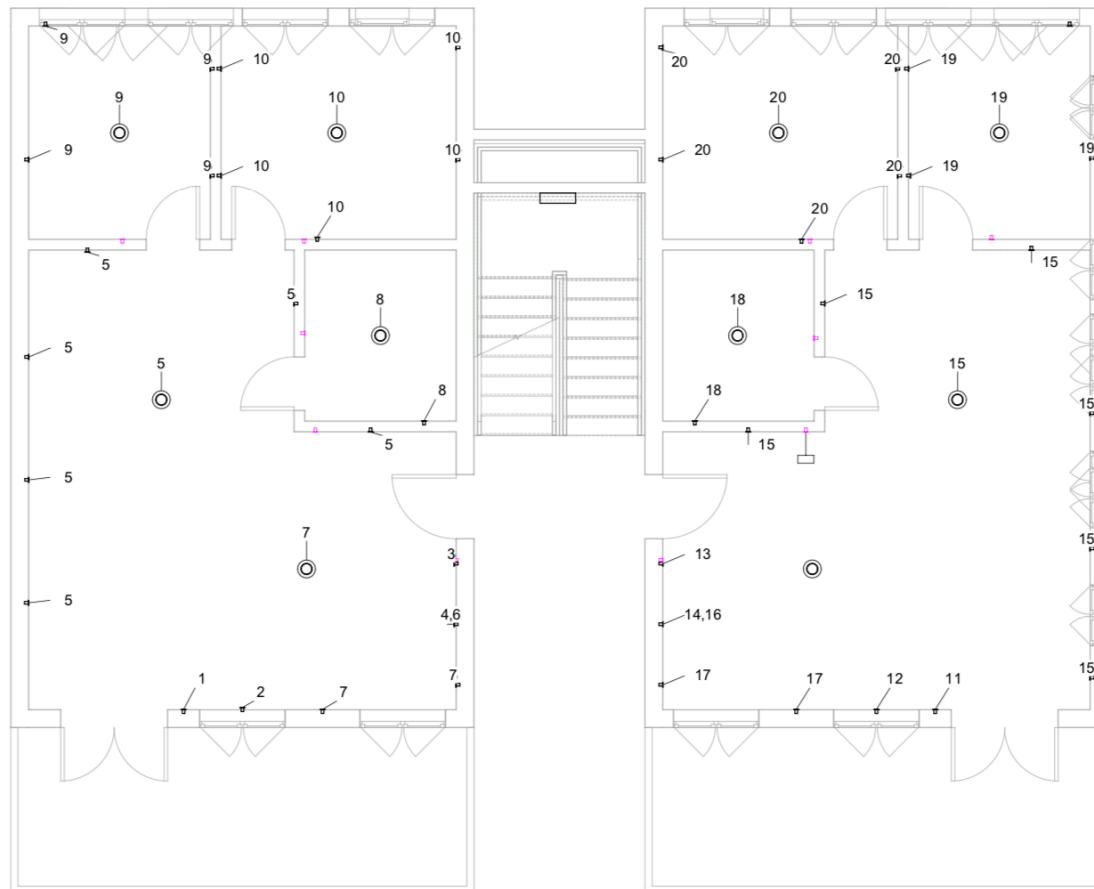




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Consultant
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Scale	3/4" = 1'-0"
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Cal Poly, San Luis Obispo

Solar Decathlon

Plan View with Circuits

Project Number	1
Date	05/21/21
Drawn By	Carina Monaco
Checked By	N/A

E3

Scale $1/2" = 1'-0"$

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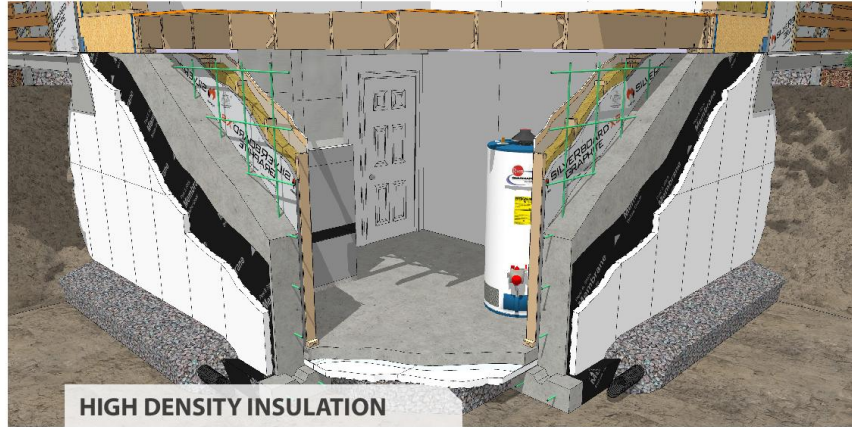


Consultant
Address
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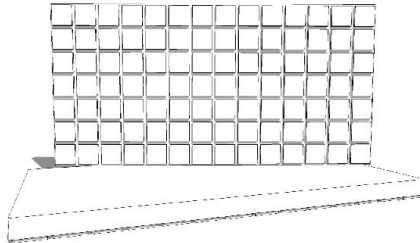
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Multipurpose EPS Insulation Panels



Amvic's multipurpose rigid insulation is a Do-it-yourself (DIY) molded panel using closed cell Expanded Polystyrene (EPS) with one flat face. The second face of the panel has bi-directional channels that can be used as either venting or water drainage, depending on the application.

The combination of high density EPS and moisture management pattern offers a highly versatile product.



Amvic Advantage

- Suitable for use in both above and below grade applications in residential, commercial, agricultural and industrial construction.
- Exceptional Long-Term Thermal Resistance (LTTR) and increased R-Value in lower temperatures.
- High vapor permeance allowing wall assemblies to dry over time.
- No off-gassing and does not contain HFCs, CFCs or HCFCs.
- Each panel is easy to handle due to the low weight, smaller size and can be easily cut.
- Provides additional protection to the waterproofing during the backfill stage when used on exterior of foundation wall.
- Load capacity of panels is 3000 pounds per square foot.

7 APRIL 2020

501 McNicoll Avenue Toronto, ON, CA, M2H 2E2
Toll Free: 1 (877) 470-9991 • Fax: (416) 759-7402

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BUILD TO A HIGHER STANDARD

PRODUCT DATA SHEET

MULTIPURPOSE EPS

Physical Properties Table

Specification for Rigid Polystyrene Insulation	CAN/ULC-S701 ASTM C578	Type 2 Type II
Thermal Resistance	ASTM C518 @ 75°F (24°C)	10 F.ft ² .hr/Btu (1.76 m ² K/W)
Compressive Strength	ASTM D1621	22 psi (152 kPa)
Water Absorption (Max.)	ASTM D2842	3%
Water Vapor Permeance	ASTM E96	1.47 US perm (84.1 ng/Pa.s.m ²)
Flexural Strength	ASTM C203	39.6 psi (273 kPa)
Dimensional Stability (Max.)	ASTM D2126	1.50%
Limiting Oxygen Index	ASTM D2863	>24.0%
Density		1.5 lb/ft ³ (22 kg/m ³)

Availability

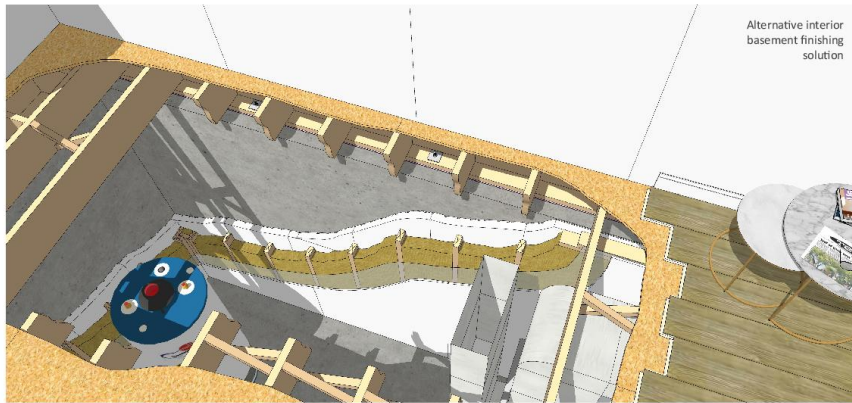
Amvic's multipurpose EPS panels come in 2x4' (610x12919mm) sheet size and are 2-3/8" (60mm) thick.

Applications

- Interior of foundation walls
- Exterior of foundation walls
- Frost walls
- Exterior above grade walls
- Roofs

Warranty

Amvic supports building owners, designers and contractors by offering a 20-year, limited thermal warranty on Amvic's multipurpose EPS panels. This warranty is available to the building owner at the time the building is completed and is transferable to any subsequent owner during the 20-year period.

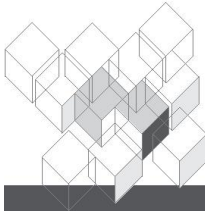


Below Grade Interior Installation

- Foam plastic (EPS) insulation is permitted in residential construction provided it is protected from the interior space by an approved thermal barrier such as 1/2" (13mm) gypsum (drywall) board, high density 2" (51mm) mineral wool or 5.5" (140mm) mineral wool batt insulation with 2x6 wood stud wall.

Below Grade Exterior Installation

- Once the water/damp proofing is installed and cured, starting at a corner, apply a quarter size spot of EPS compatible adhesive on the channeled side of the board, and attach the board so that the channels are placed in the vertical plane to the foundation wall.
- The top of the panel should be placed flush with the underside of the sill plate. Appropriate flashing details at this location are required.
- The bottom edge of the panel should have a 1/4" to 1/2" (6mm to 13mm) gap between the top of the footing to ensure proper drainage to the drainage system.



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amvic
building system



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THIS IS GREENFIBER® ALL BORATE LOOSE FILL FORMULA INSULATION

Application Coverage Chart			30 lbs. (13.6 kg)			INS765LD	
R-Value at 75° F Mean Temp. Valor de resistencia térmica (valor R) a 75 F de temperatura media	Minimum Thickness (inches) Espesor mínimo (en pulgadas)		Net Coverage (no adjustment for framing) Cubertura neta (sin compensación para la estructura)			Net Coverage (adjusted for 2" x 6" framing on 16" centers) Cubertura neta (con compensación para una estructura de 2" x 6" en centros de 16")	
	Initial Installed Thickness Espesor inicial instalado	Settled Thickness Espesor asentado	Maximum Sq. Ft. per Bag Pies cuadrados máximos por bolsa	Minimum Bags per 1,000 Sq. Ft. Cantidad mínima de bolsas por 1,000 pies cuadrados	Minimum Weight per Sq. Ft. Peso mínimo por pie cuadrado	Maximum Sq. Ft. per Bag Pies cuadrados máximos por bolsa	Minimum Bags per 1,000 Sq. Ft. Cantidad mínima de bolsas por 1,000 pies cuadrados
11	3.36	3.02	100.8	9.9	0.298	111.3	9.0
13	3.99	3.59	83.5	12.0	0.359	92.2	10.8
19	5.86	5.27	54.3	18.4	0.552	59.6	16.8
22	6.77	6.10	45.9	21.8	0.653	49.7	20.1
26	7.99	7.19	37.8	26.4	0.793	40.5	24.7
30	9.19	8.27	32.0	31.2	0.937	33.9	29.5
32	9.79	8.81	29.6	33.7	1.01	31.3	32.0
38	11.57	10.41	24.1	41.4	1.24	25.3	39.6
40	12.16	10.94	22.7	44.1	1.32	23.7	42.2
44	13.33	11.99	20.2	49.6	1.49	21.0	47.6
48	14.49	13.04	18.1	55.2	1.66	18.8	53.2
49	14.78	13.30	17.7	56.6	1.70	18.3	54.6
50	15.07	13.57	17.2	58.1	1.74	17.8	56.1
60	17.96	16.16	13.7	73.1	2.19	14.1	71.0

THE ABOVE COVERAGE CHART IS BASED ON A NOMINAL BAG WEIGHT OF 30 LBS USING A VOLUMATIC III, 3rd GEAR AND 8" GATE. THE CHART IS BASED ON SETTLED THICKNESS AND IS FOR ESTIMATING PURPOSES ONLY. JOB CONDITIONS, APPLICATION TECHNIQUES, EQUIPMENT, AND SETTINGS CAN INFLUENCE ACTUAL COVERAGE. ACTUAL COVERAGE MAY VARY BASED ON CONDITIONS AND IS NOT GUARANTEED BY THE MANUFACTURER. DO NOT EXCEED MAXIMUM SQUARE FEET COVERAGE PER BAG. THE APPLICATOR MUST INSTALL BOTH THE MINIMUM NUMBER OF BAGS PER 1000 SQ. FT. AND THE MINIMUM INSTALLED THICKNESS TO INSURE THE STATED R-VALUE HAS BEEN REACHED. FAILURE TO MEET BOTH THESE REQUIREMENTS MAY PREVENT THE ACHIEVEMENT OF THE SPECIFIED R-VALUE. THIS PRODUCT IS INTENDED FOR DRY APPLICATION ONLY. DO NOT ADD WATER TO THIS PRODUCT MINIMUM. NET WEIGHT IS 28.5 LBS.

Dry Dense Pack Sidewall Applications (3.5 pcf minimum installed density) 30 lbs. (13.6 kg) INS765LD						
Thermal Resistance (R value) Resistencia térmica a (R)	Framing Estructura	Installed Thickness (inches) Espesor instalado (pulgadas)	Minimum Wt. Per Square Foot lb/ft ² Peso mínimo por pie cuadrado lb/ft ²	Maximum Coverage Per Bag (No Adjustment for Framing) ft ² /Bag Cubertura máxima por bolsa (sin compensación para la estructura) ft ² /Bag	Maximum Coverage Per Bag (Adjusted for Framing) ft ² /Bag Cubertura máxima por bolsa (con compensación para la estructura) ft ² /Bag	
					(16" oc)	(24" oc)
13	2x4	3.5	1.02	29.39	32.4	31.3
21	2x6	5.5	1.60	18.70	20.6	19.9

THIS COVERAGE CHART IS FOR DRY APPLICATIONS ONLY AND IS BASED ON THE KRENDL KS200, WITH MATERIAL APPLIED DRY, FOR MAXIMUM COVERAGE PER BAG (ADJUSTED FOR FRAMING), THE FRAMING FACTOR FOR 16" OC STUD SPACING IS 9.375%; FOR 24" OC STUD SPACING THE FRAMING FACTOR IS 6.25%.

GreenFiber provides outstanding thermal performance, fire-resistance and sound control. Consisting of up to 85% recycled content, GreenFiber Insulation is specially treated for flame resistance.

R-value means resistance to heat flow - the higher the R-value, the greater the insulation power.

CERTIFICATION:

This insulation has been installed in conformance with the above recommendations, to provide a value of R-_____ using _____ bags of this insulation to cover _____ square feet of area.

Builder's Signature: _____

Company Name: _____

Date: _____

Applicator's Signature: _____

Company Name: _____

Date: _____

FOR MORE INFORMATION CONTACT GREENFIBER:

800.228.0024

greenfiber.info@greenfiber.com

GreenFiber Corporate Office
5500 77 Center Drive, Suite 100
Charlotte NC 28217
www.greenfiber.com

MANUFACTURING LOCATIONS:







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Tampa, FL 33605
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UL Classified
see complete marking on back of packaging












PM-6.3-327 Rev B 01/16

Multi V Compatible Ducted Fan Coil Unit Offerings													
Visual	Style	Model #	Nominal Tonnage	Nominal Cooling Capacity	Nominal Heating Capacity	MCA	MOCP	Max Power Input (W)	L / M / H Power Input (W) at Factory Default	L / M / H CFM at High Mode (Factory Default)	Dimensions (L x W x H)	Operating Weight (lbs.)	
	Low Static Ducted Concealed ESP Range = 0" to 0.19"	ARNU073L1G4	5/8	7,500	8,500	0.5	15	40	24 / 28 / 31	200 / 230 / 270	28" x 28" x 8"	39	
		ARNU093L1G4	3/4	9,600	10,900	1		85	24 / 29 / 29	200 / 250 / 320	36" x 28" x 8"	51	
		ARNU123L2G4	1	12,300	13,600				29 / 34 / 41	250 / 310 / 360			
		ARNU153L2G4	1-1/4	15,400	17,100				34 / 41 / 56	310 / 360 / 450			
		ARNU183L2G4	1-1/2	19,100	21,500	1.2		115	41 / 56 / 71	360 / 450 / 530	44" x 23" x 8"	60	
ARNU243L3G4	2	24,200	27,300	48 / 63 / 103	430 / 570 / 710								
	Mid Static Ducted Concealed (M1 Chassis) ESP Range = 0.08" to 0.59"	ARNU073M1A4	5/8	7,500	8,500	2.0	15	190	25 / 30 / 39	211 / 279 / 361	40" x 29" x 11"	56	
		ARNU093M1A4	3/4	9,600	10,900			26 / 32 / 40	229 / 296 / 376	59			
		ARNU123M1A4	1	12,300	13,600			31 / 38 / 46	262 / 328 / 392				
		ARNU153M1A4	1-1/4	15,400	17,100			46 / 53 / 67	328 / 392 / 570				
		ARNU183M1A4	1-1/2	19,100	21,500			55 / 63 / 85	392 / 556 / 638				
ARNU243M1A4	2	24,200	27,300	58 / 74 / 91	556 / 638 / 703								
	High Static Ducted Concealed (M2 Chassis) ESP Range = 0.16" to 0.71"	ARNU073M2A4	5/8	7,500	8,500	2.9	15	430	21 / 29 / 38	294 / 381 / 468	50" x 28" x 11"	83	
		ARNU093M2A4	3/4	9,600	10,900			21 / 29 / 38	294 / 381 / 468				
		ARNU123M2A4	1	12,300	13,600			25 / 34 / 43	337 / 425 / 512				
		ARNU153M2A4	1-1/4	15,400	17,100			25 / 34 / 43	337 / 425 / 512				
		ARNU183M2A4	1-1/2	19,100	21,500			34 / 43 / 67	425 / 512 / 673				
	ARNU243M2A4	2	24,200	27,300	34 / 43 / 67	425 / 512 / 623	87						
	Mid Static Ducted Concealed (M2 Chassis) ESP Range = 0.16" to 0.71"	ARNU283M2A4	2-1/2	28,000	31,500	57 / 88 / 123		528 / 676 / 845					
		ARNU363M2A4	3	36,200	40,600	88 / 123 / 184		676 / 845 / 1,031					
		ARNU423M2A4	3-1/2	42,000	47,000	136 / 193 / 231		888 / 1,076 / 1,260					
			High Static Ducted Concealed (M3 Chassis) ESP Range = 0.16" to 0.79"	ARNU283M3A4	2-1/2	28,000		31,500	3.1	15	650	60 / 83 / 109	837 / 1,017 / 1,250
ARNU483M3A4				4	48,100	54,200	75 / 107 / 172	918 / 1,191 / 1,482					
	High Static Ducted Concealed (B8 Chassis) **6 & 8-Ton Units require 2 Ports on HR boxes** ESP Range = 0.23" to 0.98"		ARNU543M3A4	4-1/2	54,000	61,400	6.5	15	800	172 / 215 / 260	1,482 / 1,614 / 1,744	62" x 29" x 18"	192
			ARNU363B8A4	3	36,200	40,600			403 / 420 / 478	1,066 / 1,317 / 1,730			
			ARNU423B8A4	3-1/2	42,000	43,800			465 / 497 / 528	1,123 / 1,458 / 1,914			
		ARNU483B8A4	4	48,100	51,200	482 / 500 / 538			1,200 / 1,518 / 2,019				
		ARNU763B8A4**	6	76,400	86,000	505 / 505 / 765			1,766 / 1,766 / 2,260				
	Vertical/Left Ducted ESP Range = 0.1" to 1.0"	ARNU963B8A4**	8	95,900	107,500	1.4	15	228	750 / 750 / 800	2,260 / 2,260 / 2,542	18" x 25" x 50"	117	
		ARNU123NJA4	1	12,000	13,500			47 / 64 / 80	380 / 480 / 530				
		ARNU183NJA4	1-1/2	18,000	20,000			64 / 80 / 90	480 / 530 / 580				
		ARNU243NJA4	2	24,000	27,000			64 / 96 / 120	480 / 640 / 710				
		ARNU303NJA4	2-1/2	30,000	34,000			94 / 133 / 180	630 / 800 / 880				
		ARNU363NJA4	3	36,000	40,000	2.25		366	133 / 180 / 230	800 / 880 / 990	25" x 22" x 56"	165	
		ARNU423NKA4	3-1/2	42,000	46,000				186 / 215 / 260	1,000 / 1,100 / 1,250			
		ARNU483NKA4	4	48,000	54,000				186 / 264 / 330	1,000 / 1,260 / 1,400			
		ARNU543NKA4	4-1/2	54,000	60,000				264 / 312 / 370	1,260 / 1,400 / 1,475			





Purpose for 11/1/2020 Update: LG has recently re-classified certain models as "mid static ducted" although none of the data or performance changed. There is also a discontinuation announcement of models ARNU363M3A4 (3-Ton) and ARNU423M3A4 (3.5-Ton) which will be discontinued no later than December 28, 2020. The end of life plan for these units includes a final date to place orders of November 30, 2020. All inventory for these discontinued models will be zero as of December 28, 2020.

Purpose for 2/1/2021 Update: LG has recently added ceiling suspended ductless indoor units to the Multi V product line. These units come in 1.5, 2, 3, and 4-Ton nominal sizes in respective model #'s ARNU183V1A4, ARNU243V1A4, ARNU363V2A4, and ARNU483V2A4. These models do not replace any existing indoor unit offering.

Multi V Compatible Non-Ducted Fan Coil Unit Offerings														
Visual	Style	Model #	Nominal Tonnage	Nominal Cooling Capacity	Nominal Heating Capacity	MCA	MOCP	Max Power Input (W)	L / M / H Power Input (W) at Factory Default	L / M / H CFM at High Mode (Factory Default)	Dimensions (L x W x H)	Operating Weight (lbs.)		
	High Wall Mount (Standard White)	ARNU053SJA4	1/2	5,500	6,100	0.31	15	30	9 / 10 / 11	208 / 230 / 240	33" x 6" x 13"	19		
		ARNU073SJA4	5/8	7,500	8,500				9 / 11 / 12	208 / 240 / 254				
		ARNU093SJA4	3/4	9,600	10,900				9 / 12 / 13	208 / 254 / 275				
		ARNU123SJA4	1	12,300	13,600				11 / 13 / 15	240 / 254 / 300				
		ARNU153SJA4	1-1/4	15,400	17,100				11 / 18 / 23	240 / 336 / 371				
		ARNU183SKA4	1-1/2	19,100	21,500	0.65		53	16 / 26 / 32	371 / 424 / 494	40" x 7" x 14"	27		
		ARNU243SKA4	2	24,200	27,300				16 / 26 / 39	371 / 449 / 537				
		ARNU303SVA4	2-1/2	30,000	32,000				31 / 43 / 54	600 / 706 / 812				
		ARNU363SVA4	3	35,500	37,000				36 / 51 / 85	671 / 812 / 918				
		ARNU483TMC4	4	48,100	46,115				66 / 80 / 120	883 / 953 / 1,130				
	1-Way Ceiling Cassette	ARNU073TUD4	5/8	7,500	8,500	0.23	15	40	16 / 18 / 20	226 / 258 / 290	44" x 20" x 8"	33		
		ARNU093TUD4	3/4	9,600	10,900				18 / 20 / 22	290 / 304 / 325				
		ARNU123TUD4	1	12,300	13,600				20 / 22 / 24	290 / 325 / 353				
		ARNU183TTD4	1-1/2	19,100	21,500	0.38		70	24 / 28 / 38	385 / 427 / 470	56" x 20" x 8"	42		
		ARNU243TTD4	2	24,200	24,200				26 / 33 / 51	406 / 470 / 515				
		ARNU483TMC4	4	48,100	46,115				66 / 80 / 120	883 / 953 / 1,130				
	2-Way Ceiling Cassette	ARNU183TSA4	1-1/2	19,100	21,500	0.84	15	70	24 / 29 / 34	348 / 381 / 417	44" x 28" x 9"	40		
		ARNU243TSA4	2	24,200	27,300				25 / 30 / 40	364 / 438 / 512				
	4-Way Ceiling Cassette (2' x 2' Chassis)	ARNU053TRD4	1/2	5,500	6,100	0.25	15	30	11 / 12 / 13	212 / 247 / 265	24" x 24" x 10"	29		
		ARNU073TRD4	5/8	7,500	8,500				11 / 12 / 13	212 / 247 / 265				
		ARNU093TRD4	3/4	9,600	10,900				12 / 13 / 14	251 / 265 / 283				
		ARNU123TRD4	1	12,300	13,600				13 / 15 / 17	247 / 283 / 307	24" x 24" x 11"	35		
		ARNU153TQD4	1-1/4	15,400	17,100				18 / 21 / 24	328 / 353 / 388				
		ARNU183TQD4	1-1/2	19,100	21,500				19 / 22 / 25	353 / 388 / 396				
	4-Way Ceiling Cassette (3' x 3' Chassis)	ARNU073TNA4	5/8	7,500	8,500	0.71	15	144	12 / 15 / 18	388 / 424 / 459	33" x 33" x 10"	54		
		ARNU093TNA4	3/4	9,600	10,900				12 / 15 / 19	388 / 424 / 477				
		ARNU123TNA4	1	12,300	13,600				14 / 17 / 22	242 / 459 / 494				
		ARNU153TNA4	1-1/4	15,400	17,100				14 / 17 / 25	424 / 459 / 530				
		ARNU183TNA4	1-1/2	19,100	21,500				14 / 18 / 27	424 / 530 / 565				
		ARNU243TNA4	2	24,200	27,300	1.6			30 / 38 / 51	600 / 671 / 742	33" x 33" x 12"	59		
		ARNU283TMA4	2-1/2	28,000	31,500				31 / 43 / 52	635 / 741 / 812				
		ARNU363TMA4	3	36,200	40,600				34 / 47 / 64	706 / 812 / 918				
		ARNU423TMC4	3-1/2	42,000	43,800				53 / 75 / 104	812 / 918 / 1,059				
		ARNU483TMC4	4	48,100	46,115				66 / 80 / 120	883 / 953 / 1,130				
	Picture Frame Wall Mount	ARNU093SFA4	3/4	9,600	10,900	0.4	15	35	10 / 16 / 28	148 / 222 / 286	24" x 6" x 24"	34		
		ARNU123SFA4	1	12,300	13,600				12 / 20 / 32	212 / 272 / 328				
	Ceiling Suspended	ARNU183V1A4	1-1/2	19,100	21,500	1.21	15	130	23 / 20 / 17	477 / 441 / 424	48" x 28" x 10"	64		
		ARNU243V1A4	2	24,200	27,300				25 / 21 / 17	495 / 459 / 424				
		ARNU363V2A4	3	36,200	40,600			184	84 / 77 / 66	954 / 848 / 706	63" x 28" x 10"	82		
		ARNU483V2A4	4	48,100	51,200				91 / 79 / 66	1,024 / 848 / 706				
	Mirror Finish High Wall Mount	ARNU053SJR4	1/2	5,500	6,100	0.31	15	30	9 / 10 / 11	208 / 230 / 240	33" x 6" x 13"	21		
		ARNU073SJR4	5/8	7,500	8,500				9 / 11 / 12	208 / 240 / 254				
		ARNU093SJR4	3/4	9,600	10,900				9 / 12 / 13	208 / 254 / 275				
		ARNU123SJR4	1	12,300	13,600				11 / 13 / 15	240 / 254 / 300				
		ARNU153SJR4	1-1/4	15,400	17,100	0.65		53	11 / 18 / 23	240 / 336 / 371	40" x 7" x 14"	30		
		ARNU183SKR4	1-1/2	19,100	21,500				16 / 26 / 32	371 / 424 / 494				
		ARNU243SKR4	2	24,200	27,300				16 / 26 / 39	371 / 449 / 537				
		ARNU483TMC4	4	48,100	46,115				66 / 80 / 120	883 / 953 / 1,130				
	Floor Standing With Case	ARNU073CEA4	5/8	7,500	8,500	1.0	15	85	- / - / 85	229 / 265 / 300	42" x 8" x 25"	60		
		ARNU093CEA4	3/4	9,600	10,900				- / - / 85	265 / 300 / 335				
		ARNU123CEA4	1	12,300	13,600				- / - / 85	300 / 335 / 371				
		ARNU153CEA4	1-1/4	15,400	17,100	1.2		115	- / - / 85	335 / 353 / 406	53" x 8" x 25"	75		
		ARNU183CFA4	1-1/2	19,100	21,500				- / - / 115	424 / 494 / 565				
		ARNU243CFA4	2	24,200	27,300				- / - / 115	464 / 565 / 635				

















Purpose for 2/1/2021 Update: LG has recently added ceiling suspended ductless indoor units to the Multi V product line. These units come in 1.5, 2, 3, and 4-Ton nominal sizes in respective model #'s ARNU183V1A4, ARNU243V1A4, ARNU363V2A4, and ARNU483V2A4. These models do not replace any existing indoor unit offering.

LG Multi V Outdoor Unit Product Offering as of February 1, 2021

Multi V Compatible Air Source Condensing Unit Offerings (Performance & Physical Summary)																				LG	
Visual	Model #	Style	Electrical	First Chassis	Second Chassis	Third Chassis	Nominal Tonnage	Nominal Cooling Capacity	Nominal Heating Capacity	Non-Ducted IDU's					Ducted IDU's					Dimensions (W x D x H) (min) dimensions shown for multi-chassis systems assuming 1" between each ODU chassis	Operating Weight (lbs.)
										Mix of Ducted & Non-Ducted IDU's (Weighted Average between Non-Ducted and Ducted Ratings)											
										EER	IEER(SEER)	SCHE(HSPF)	High COP	Low COP	EER	IEER(SEER)	SCHE(HSPF)	High COP	Low COP		
	ARUN024GSS4	Heat Pump Only	208-230V/1ø	ARUN024GSS4	-	-	2	24,000	27,000	10.7	(17.0)	(10.0)	-	-	12.2	(15.8)	(8.6)	-	-	37-13/32" x 15-11/32" x 32-27/32"	159
	ARUN038GSS4	Heat Pump Only		ARUN038GSS4	-	-	3	39,500	44,000	11.5	(17.0)	(9.0)	-	-	11.5	(17.0)	(9.0)	-	-	37-13/32" x 15-11/32" x 54-11/32"	207
	ARUN036GSS5	Heat Pump or Heat Recovery		ARUN036GSS5	-	-	3	36,000	42,000	15.5	(23.0)	(12.0)	-	-	13	(18.3)	(11.4)	-	-	37-13/32" x 15-11/32" x 54-11/32"	263
	ARUN048GSS4	Heat Pump Only		ARUN048GSS4	-	-	4	50,000	56,500	10.5	(17.0)	(9.5)	-	-	10.5	(17.0)	(9.5)	-	-	37-13/32" x 15-11/32" x 54-11/32"	207
	ARUN048GSS5	Heat Pump or Heat Recovery		ARUN048GSS5	-	-	4	48,000	54,000	13.5	(23.3)	(12.0)	-	-	13	(17.5)	11	-	-	37-13/32" x 15-11/32" x 54-11/32"	263
	ARUN060GSS4	Heat Pump Only	208-230V/1ø	ARUN060GSS4	-	-	5	60,000	61,500	10.0	(18.9)	(10.9)	-	-	10.0	(16.5)	(10.0)	-	-	37-13/32" x 15-11/32" x 54-11/32"	260
	ARUB060GSS4	Heat Recovery Only		ARUB060GSS4	-	-	5	60,000	64,000	10.0	(18.9)	(10.9)	-	-	10.0	(16.5)	(10.0)	-	-	37-13/32" x 15-11/32" x 54-11/32"	260
	ARUM072BTE5			ARUM072BTE5	-	-	6	72,000	81,000	13.4	28.4	28.5	3.83	2.66	13.0	23.6	26.1	3.48	2.49	36-5/8" x 29-29/32" x 66-17/32"	430
	ARUM096BTE5			ARUM096BTE5	-	-	8	96,000	108,000	14.4	33.0	32.0	4.33	2.85	13.5	25.1	27.0	3.66	2.73	48-13/16" x 29-29/32" x 66-17/32"	507
	ARUM121BTE5			ARUM121BTE5	-	-	10	119,700	135,000	13.1	29.6	31.0	3.97	2.74	12.5	24.6	26.4	3.46	2.53	48-13/16" x 29-29/32" x 66-17/32"	507
	ARUM144BTE5		208-230V/3ø	ARUM144BTE5	-	-	12	144,000	162,000	12.5	28.6	27.5	3.84	2.67	12.1	23.0	25.9	3.52	2.48	48-13/16" x 29-29/32" x 66-17/32"	639
	ARUM168BTE5			ARUM168BTE5	-	-	14	168,000	189,000	11.7	25.4	27.0	3.57	2.45	11.1	21.9	23.6	3.20	2.38	48-13/16" x 29-29/32" x 66-17/32"	639
	ARUM192BTE5			ARUM192BTE5	-	-	16	192,000	216,000	12.4	25.9	26.6	3.75	2.64	11.0	23.0	25.3	3.30	2.41	48-13/16" x 29-29/32" x 66-17/32"	659
	ARUM216BTE5			ARUM216BTE5	-	-	18	216,000	243,000	11.2	24.8	26.0	3.53	2.66	10.7	22.4	23.4	3.20	2.34	48-13/16" x 29-29/32" x 66-17/32"	666
	ARUN241BTE5			ARUN241BTE5	-	-	20	233,100	243,000	10.4	22.5	26.0	3.35	2.52	10.4	22.7	23.0	3.20	2.26	48-13/16" x 29-29/32" x 66-17/32"	666
	ARUM072DTE5			ARUM072DTE5	-	-	6	72,000	81,000	13.4	28.4	28.5	3.83	2.66	13.0	23.6	26.1	3.48	2.49	36-5/8" x 29-29/32" x 66-17/32"	430
	ARUM096DTE5			ARUM096DTE5	-	-	8	96,000	108,000	14.4	33.0	32.0	4.33	2.85	13.5	25.1	27.0	3.66	2.73	48-13/16" x 29-29/32" x 66-17/32"	507
	ARUM121DTE5			ARUM121DTE5	-	-	10	119,700	135,000	13.1	29.6	31.0	3.97	2.74	12.5	24.6	26.4	3.46	2.53	48-13/16" x 29-29/32" x 66-17/32"	507
	ARUM144DTE5			ARUM144DTE5	-	-	12	144,000	162,000	12.5	28.6	27.5	3.84	2.67	12.1	23.0	25.9	3.52	2.48	48-13/16" x 29-29/32" x 66-17/32"	639
	ARUM168DTE5			ARUM168DTE5	-	-	14	168,000	189,000	11.7	25.4	27.0	3.57	2.45	11.1	21.9	23.6	3.20	2.38	48-13/16" x 29-29/32" x 66-17/32"	639
	ARUN192DTE5			ARUN192DTE5	-	-	16	192,000	216,000	12.4	25.9	26.6	3.75	2.64	11.0	23.0	25.3	3.30	2.41	48-13/16" x 29-29/32" x 66-17/32"	659
	ARUM216DTE5			ARUM216DTE5	-	-	18	216,000	243,000	11.2	24.8	26.0	3.53	2.66	10.7	22.4	23.4	3.20	2.34	48-13/16" x 29-29/32" x 66-17/32"	666
	ARUN241DTE5			ARUN241DTE5	-	-	20	233,100	243,000	10.4	22.5	26.0	3.35	2.52	10.4	22.7	23.0	3.20	2.26	48-13/16" x 29-29/32" x 66-17/32"	666
	ARUN096BTE5	ARUM168BTE5		ARUM192BTE5	ARUM216BTE5	-	22	264,000	297,000	12.5	22.0	25.0	3.56	2.52	11.5	21.5	24.6	3.38	2.38	97-5/8" (min) x 29-29/32" x 66-17/32"	507 + 639
	ARUM096BTE5	ARUM168BTE5		ARUM192BTE5	ARUM216BTE5	-	24	288,000	324,000	12.2	22.0	24.0	3.55	2.50	11.3	21.0	23.5	3.33	2.35	97-5/8" (min) x 29-29/32" x 66-17/32"	507 + 659
	ARUM121BTE5	ARUM096BTE5		ARUM216BTE5	ARUM216BTE5	-	26	312,000	351,000	11.0	22.0	24.0	3.53	2.48	11.0	21.0	21.0	3.25	2.30	97-5/8" (min) x 29-29/32" x 66-17/32"	507 + 666
ARUM136BTE5	ARUM121BTE5	ARUM168BTE5	ARUM216BTE5	-	28	336,000	378,000	9.8	20.5	23.2	3.52	2.36	10.8	20.5	20.5	3.24	2.25	97-5/8" (min) x 29-29/32" x 66-17/32"	507 + 666		
ARUM144BTE5	ARUM168BTE5	ARUM216BTE5	ARUM216BTE5	-	30	360,000	405,000	10.8	20.0	22.6	3.51	2.30	10.2	19.5	20.2	3.23	2.21	97-5/8" (min) x 29-29/32" x 66-17/32"	639 + 666		
ARUM168BTE5	ARUM168BTE5	ARUM216BTE5	ARUM216BTE5	-	32	384,000	432,000	10.0	19.0	23.0	3.40	2.28	9.8	19.3	19.5	3.22	2.20	97-5/8" (min) x 29-29/32" x 66-17/32"	639 + 666		
	ARUN192BTE5		208-230V/3ø	ARUN192BTE5	-	-	34	408,000	459,000	9.8	18.8	22.0	3.34	2.26	9.7	19.0	19.0	3.22	2.18	97-5/8" (min) x 29-29/32" x 66-17/32"	659 + 666
	ARUM096DTE5			ARUM096DTE5	-	-	22	264,000	297,000	12.5	22.0	25.0	3.56	2.52	11.5	21.5	24.6	3.38	2.38	97-5/8" (min) x 29-29/32" x 66-17/32"	507 + 639
	ARUN096DTE5			ARUN192DTE5	-	-	24	288,000	324,000	12.2	22.0	24.0	3.55	2.50	11.3	21.0	23.5	3.33	2.35	97-5/8" (min) x 29-29/32" x 66-17/32"	507 + 659
	ARUM096DTE5	ARUM168DTE5		ARUM216DTE5	-	26	312,000	351,000	11.0	22.0	24.0	3.53	2.48	11.0	21.0	21.0	3.25	2.30	97-5/8" (min) x 29-29/32" x 66-17/32"	507 + 666	
	ARUM121DTE5			ARUM121DTE5	-	-	28	336,000	378,000	9.8	20.5	23.2	3.52	2.36	10.8	20.5	20.5	3.24	2.25	97-5/8" (min) x 29-29/32" x 66-17/32"	507 + 666
	ARUM144DTE5			ARUM144DTE5	-	-	30	360,000	405,000	10.8	20.0	22.6	3.51	2.30	10.2	19.5	20.2	3.23	2.21	97-5/8" (min) x 29-29/32" x 66-17/32"	639 + 666
	ARUM168DTE5			ARUM168DTE5	-	-	32	384,000	432,000	10.0	19.0	23.0	3.40	2.28	9.8	19.3	19.5	3.22	2.20	97-5/8" (min) x 29-29/32" x 66-17/32"	639 + 666
	ARUM192DTE5	ARUM168DTE5		ARUM216DTE5	-	34	408,000	459,000	9.8	18.8	22.0	3.34	2.26	9.7	19.0	19.0	3.22	2.18	97-5/8" (min) x 29-29/32" x 66-17/32"	659 + 666	
	ARUM121BTE5	ARUM121BTE5		ARUM192BTE5	ARUM216BTE5	36	430,500	486,000	9.8	19.8	21.5	3.28	2.32	10.5	20.0	19.0	3.22	2.17	146-7/16" (min) x 29-29/32" x 66-17/32"	507 + 507 + 659	
	ARUM121BTE5	ARUM121BTE5		ARUM168BTE5	ARUM216BTE5	38	455,700	513,000	9.7	19.2	21.0	3.23	2.30	9.8	18.5	18.8	3.22	2.15	146-7/16" (min) x 29-29/32" x 66-17/32"	507 + 507 + 666	
	ARUM121BTE5	ARUM121BTE5		ARUM192BTE5	ARUM216BTE5	40	476,700	540,000	9.6	19.0	19.0	3.21	2.27	9.7	18.0	18.5	3.21	2.12	146-7/16" (min) x 29-29/32" x 66-17/32"	507 + 639 + 666	
	ARUM144BTE5			ARUM144BTE5	-	-	42	504,000	567,000	9.6	18.6	18.0	3.21	2.22	9.6	17.5	18.0	3.21	2.10	146-7/16" (min) x 29-29/32" x 66-17/32"	507 + 639 + 666
	ARUM121DTE5			ARUM121DTE5	-	-	36	430,500	486,000	9.8	19.8	21.5	3.28	2.32	10.5	20.0	19.0	3.22	2.17	146-7/16" (min) x 29-29/32" x 66-17/32"	507 + 507 + 659
	ARUM121DTE5	ARUM121DTE5		ARUM192DTE5	ARUM216BTE5	38	455,700	513,000	9.7	19.2	21.0	3.23	2.30	9.8	18.5	18.8	3.22	2.15	146-7/16" (min) x 29-29/32" x 66-17/32"	507 + 507 + 666	
	ARUM144DTE5			ARUM144DTE5	-	-	40	476,700	540,000	9.6	19.0	19.0	3.21	2.27	9.7	18.0	18.5	3.21	2.12	146-7/16" (min) x 29-29/32" x 66-17/32"	507 + 639 + 666
	ARUM504DTE5			ARUM168DTE5	ARUM216DTE5	42	504,000	567,000	9.6	18.6	18.0	3.21	2.22	9.6	17.5	18.0	3.21	2.10	146-7/16" (min) x 29-29/32" x 66-17/32"	507 + 639 + 666	

Purpose for 2/1/2021 Update: LG has recently added 3-ton and 4-ton condensing units (ARUM036GSS5 and ARUM048GSS5) which are capable of being operated as heat pump or heat recovery units, and have the new LGRED compressor technology for higher efficiency operation.

LG Multi V Outdoor Unit Product Offering as of February 1, 2021

LG		Multi V Compatible Air Source Condensing Unit Offerings (Electrical and Sound Summary)																		LG	
Visual	Model #	Style	Electrical	First Chassis	Second Chassis	Third Chassis	Nominal Tonnage	Compressor Motor RLA						Condenser Fan Motor FLA			MCA	MOCP	Sound Pressure Levels in dB(A)	Sound Power Levels dB(A)	
								First Chassis		Second Chassis		Third Chassis		First Chassis	Second Chassis	Third Chassis					
								Comp # 1	Comp # 2	Comp # 1	Comp # 2	Comp # 1	Comp # 2	FLA x Fan Qty.	FLA x Fan Qty.	FLA x Fan Qty.					
	ARUN024GSS4	Heat Pump Only	208-230V/1ϕ	ARUN024GSS4	-	-	2	15.3	-	-	-	-	-	0.5 x 1	-	-	19.6	30	50-52	62	
	ARUN038GSS4	Heat Pump Only		ARUN038GSS4	-	-	3	19.5	-	-	-	-	-	0.5 x 2	-	-	25	40	50-52	66	
	ARUN036GSS5	Heat Pump or Heat Recovery		ARUM036GSS5	-	-	3	18	-	-	-	-	-	0.5 x 2	-	-	23.5	40	50-53	66	
	ARUN048GSS4	Heat Pump Only	208-230V/1ϕ	ARUN048GSS4	-	-	4	23	-	-	-	-	-	0.5 x 2	-	-	30	50	51-53	67	
	ARUM048GSS5	Heat Pump or Heat Recovery		ARUM048GSS5	-	-	4	18.4	-	-	-	-	-	0.5 x 2	-	-	24	40	52-54	67	
	ARUN060GSS4	Heat Pump Only		ARUN060GSS4	-	-	5	25	-	-	-	-	-	0.5 x 2	-	-	33	50	57-59	69	
	ARUB060GSS4	Heat Recovery Only	208-230V/3ϕ	ARUB060GSS4	-	-	5	20	-	-	-	-	-	0.5 x 2	-	-	25	40	57-59	69	
	ARUM072BTE5	-		ARUM072BTE5	-	-	6	14.1	-	-	-	-	-	5.0 x 1	-	-	22.6	35	58	77	
	ARUM096BTE5	-		ARUM096BTE5	-	-	8	16.4	-	-	-	-	-	4.0 x 2	-	-	28.5	40	58	78	
	ARUM121BTE5	-	208-230V/3ϕ	ARUM121BTE5	-	-	10	18.3	-	-	-	-	-	4.0 x 2	-	-	30.9	40	59	79	
	ARUM144BTE5	-		ARUM144BTE5	-	-	12	19.8	18.3	-	-	-	-	4.0 x 2	-	-	51.1	70	60	83	
	ARUM168BTE5	-		ARUM168BTE5	-	-	14	21.2	19.1	-	-	-	-	4.0 x 2	-	-	53.6	70	61	85	
	ARUM192BTE5	-	208-230V/3ϕ	ARUM192BTE5	-	-	16	23.3	20.8	-	-	-	-	4.0 x 2	-	-	57.9	80	62	87	
	ARUM216BTE5	-		ARUM216BTE5	-	-	18	24.3	21.9	-	-	-	-	4.0 x 2	-	-	60.3	80	64	88	
	ARUM241BTE5	-		ARUM241BTE5	-	-	20	25.6	23.2	-	-	-	-	4.0 x 2	-	-	63.2	80	65	88	
	ARUM072DTE5	-	460V/3ϕ	ARUM072DTE5	-	-	6	7.8	-	-	-	-	-	3.0 x 1	-	-	12.8	20	58	77	
	ARUM096DTE5	-		ARUM096DTE5	-	-	8	9.1	-	-	-	-	-	2.5 x 2	-	-	16.4	25	58	78	
	ARUM121DTE5	-		ARUM121DTE5	-	-	10	10.7	-	-	-	-	-	2.5 x 2	-	-	18.4	25	59	79	
	ARUM144DTE5	-	460V/3ϕ	ARUM144DTE5	-	-	12	10.3	8.5	-	-	-	-	2.5 x 2	-	-	26.4	35	60	83	
	ARUM168DTE5	-		ARUM168DTE5	-	-	14	11.4	9.2	-	-	-	-	2.5 x 2	-	-	28.5	35	61	85	
	ARUM192DTE5	-		ARUM192DTE5	-	-	16	14.8	12.2	-	-	-	-	2.5 x 2	-	-	35.7	50	62	87	
	ARUM216DTE5	-	208-230V/3ϕ	ARUM216DTE5	-	-	18	15.5	13.9	-	-	-	-	2.5 x 2	-	-	38.3	50	64	88	
	ARUM241DTE5	-		ARUM241DTE5	-	-	20	16.9	15.3	-	-	-	-	2.5 x 2	-	-	41.4	50	65	88	
	ARUM264DTE5	-		ARUM264DTE5	-	-	22	21.2	19.1	16.4	-	-	-	4.0 x 2	4.0 x 2	-	53.6 + 28.5	70 + 40	63	86	
	ARUM288BTE5	-	208-230V/3ϕ	ARUM288BTE5	ARUM192BTE5	-	24	23.3	20.8	16.4	-	-	-	4.0 x 2	4.0 x 2	-	57.9 + 28.5	80 + 40	63	87	
	ARUM312BTE5	-		ARUM312BTE5	ARUM168BTE5	-	26	24.3	21.9	16.4	-	-	-	4.0 x 2	4.0 x 2	-	60.3 + 28.5	80 + 40	65	88	
	ARUM336BTE5	-		ARUM336BTE5	ARUM144BTE5	-	28	24.3	21.9	18.3	-	-	-	4.0 x 2	4.0 x 2	-	60.3 + 30.9	80 + 40	65	88	
	ARUM360BTE5	-	208-230V/3ϕ	ARUM360BTE5	ARUM121BTE5	-	30	24.3	21.9	19.8	18.3	-	-	4.0 x 2	4.0 x 2	-	60.3 + 51.1	80 + 70	66	89	
	ARUM384BTE5	-		ARUM384BTE5	ARUM108BTE5	-	32	24.3	21.9	21.2	19.1	-	-	4.0 x 2	4.0 x 2	-	60.3 + 53.6	80 + 70	66	89	
	ARUM408BTE5	-		ARUM408BTE5	ARUM096BTE5	-	34	24.3	21.9	23.3	20.8	-	-	4.0 x 2	4.0 x 2	-	60.3 + 57.9	80 + 80	66	90	
	ARUM432DTE5	-	460V/3ϕ	ARUM432DTE5	ARUM096DTE5	-	22	11.4	9.2	9.1	-	-	-	2.5 x 2	2.5 x 2	-	28.5 + 16.4	35 + 25	63	86	
	ARUM456DTE5	-		ARUM456DTE5	ARUM121DTE5	-	24	14.8	12.2	9.1	-	-	-	2.5 x 2	2.5 x 2	-	35.7 + 16.4	50 + 25	63	87	
	ARUM480DTE5	-		ARUM480DTE5	ARUM144DTE5	-	26	15.5	13.9	9.1	-	-	-	2.5 x 2	2.5 x 2	-	38.3 + 16.4	50 + 25	65	88	
	ARUM504DTE5	-	208-230V/3ϕ	ARUM504DTE5	ARUM168DTE5	-	28	15.5	13.9	10.7	-	-	-	2.5 x 2	2.5 x 2	-	38.3 + 18.4	50 + 25	65	88	
	ARUM528DTE5	-		ARUM528DTE5	ARUM192DTE5	-	30	15.5	13.9	10.3	8.5	-	-	2.5 x 2	2.5 x 2	-	38.3 + 26.4	50 + 35	66	89	
	ARUM552DTE5	-		ARUM552DTE5	ARUM216DTE5	-	32	15.5	13.9	11.4	9.2	-	-	2.5 x 2	2.5 x 2	-	38.3 + 28.5	50 + 35	66	89	
	ARUM576DTE5	-	208-230V/3ϕ	ARUM576DTE5	ARUM241BTE5	ARUM121BTE5	36	23.3	20.8	18.3	-	18.3	-	4.0 x 2	4.0 x 2	4.0 x 2	57.9 + 30.9 + 30.9	80 + 40 + 40	66	89	
	ARUM600DTE5	-		ARUM600DTE5	ARUM264BTE5	ARUM144BTE5	38	24.3	21.9	18.3	-	18.3	-	4.0 x 2	4.0 x 2	4.0 x 2	60.3 + 30.9 + 30.9	80 + 40 + 40	66	89	
	ARUM624DTE5	-		ARUM624DTE5	ARUM288BTE5	ARUM168BTE5	40	24.3	21.9	19.8	18.3	18.3	-	4.0 x 2	4.0 x 2	4.0 x 2	60.3 + 51.1 + 30.9	80 + 70 + 40	67	89	
	ARUM648DTE5	-	460V/3ϕ	ARUM648DTE5	ARUM312BTE5	ARUM192DTE5	42	24.3	21.9	21.2	19.1	18.3	-	4.0 x 2	4.0 x 2	4.0 x 2	60.3 + 53.6 + 30.9	80 + 70 + 40	67	90	
	ARUM672DTE5	-		ARUM672DTE5	ARUM336BTE5	ARUM216DTE5	36	14.8	12.2	10.7	-	10.7	-	2.5 x 2	2.5 x 2	2.5 x 2	35.7 + 18.4 + 18.4	50 + 25 + 25	66	89	
	ARUM696DTE5	-		ARUM696DTE5	ARUM360BTE5	ARUM241DTE5	38	15.5	13.9	10.7	-	10.7	-	2.5 x 2	2.5 x 2	2.5 x 2	38.3 + 18.4 + 18.4	50 + 25 + 25	67	89	
	ARUM720DTE5	-	460V/3ϕ	ARUM720DTE5	ARUM408BTE5	ARUM264DTE5	40	15.5	13.9	10.3	8.5	10.7	-	2.5 x 2	2.5 x 2	2.5 x 2	38.3 + 26.4 + 18.4	50 + 35 + 25	67	89	
	ARUM744DTE5	-		ARUM744DTE5	ARUM432DTE5	ARUM312DTE5	42	15.5	13.9	11.4	9.2	10.7	-	2.5 x 2	2.5 x 2	2.5 x 2	38.3 + 28.5 + 18.4	50 + 35 + 25	67	90	
	ARUM768DTE5	-		ARUM768DTE5	ARUM456DTE5	ARUM336DTE5	44	15.5	13.9	11.4	9.2	10.7	-	2.5 x 2	2.5 x 2	2.5 x 2	38.3 + 28.5 + 18.4	50 + 35 + 25	67	90	

Sound Pressure Level Notes applicable to all LG ODU's (See Engineering Manual for Charts and greater details):
 Measurements taken with no attenuation and the units operating at full load under a normal operating condition.
 Sound level will vary depending on a range of factors such as construction (acoustic absorption coefficient) of particular area in which the equipment is installed.
 Off-Peak Operation: Logic takes advantage of lower outdoor ambient temperatures and limits the outdoor unit fan speed during nighttime operation to lower the sound level.
 Sound levels are measured in dB(A)1/3.
 Tested in anechoic chamber per ISO Standard 3745.

Sound Power Level Notes applicable to all LG ODU's (See Engineering Manual for Charts and greater details):
 Data is valid under diffuse field conditions. Data is valid under nominal operating conditions.
 Sound level will vary depending on a range of factors such as construction (acoustic absorption coefficient) of particular area in which the equipment is installed.
 Sound power level is measured using rated conditions, and tested in a reverberation room per ISO 3741 standards.
 Reference acoustic intensity: $O_{dB} = 10E-6W/m^2$

Purpose for 2/1/2021 Update: LG has recently added 3-ton and 4-ton condensing units (ARUM036GSS5 and ARUM048GSS5) which are capable of being operated as heat pump or heat recovery units, and have the new LGRED compressor technology for higher efficiency operation.

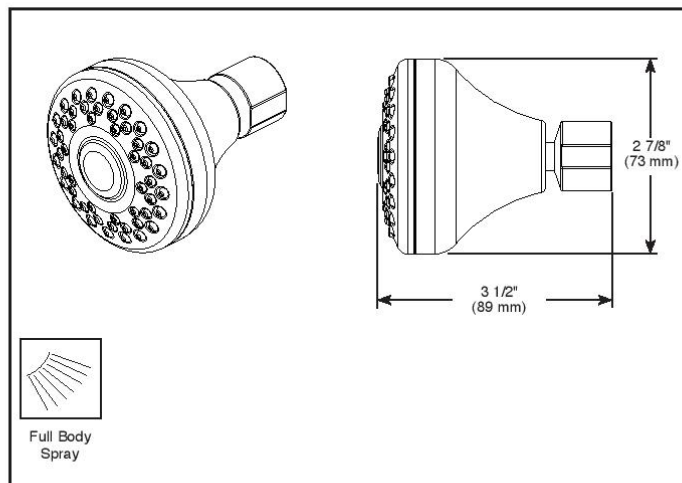
Model ARUN [024 thru 060] GSS4 and ARUM [036 and 048] GSS5 Sound Pressure Levels:
 Measurement taken 4.9' above finished floor, at a distance of 3.3' from face of fan discharge.
Model ARUM060GSS4 Sound Pressure Levels:
 Measurement taken 4.9' above finished floor, at a distance of 3.3' from face of fan discharge.
Models ARUM [072 thru 594] BTE5 / DTE5 Sound Pressure Levels:
 Measurement taken 3.3' above finished floor, and at a distance of 3.3' from face of unit.
 Sound level may be increased in static pressure mode or if an air guide is used.

Models ARUM [072 thru 594] BTE5 / DTE5 Sound Power Levels:
 Sound level may be increased in static pressure mode or if air guide is used.



Submitted Model No.: _____

Specific Features: _____



CLASSIC BASIC SHOWERHEAD

STANDARD SPECIFICATIONS

- Maximum 1.5 GPM @ 80 PSI, 5.7 L/Min @ 550 kPa
- Single spray setting
- Touch-clean spray holes

WARRANTY

- Lifetime limited warranty on parts (other than electronic parts and batteries) and finishes; or, for commercial users, for 5 years from date of purchase.
- 5 year limited warranty on electronic parts (other than batteries); or, for commercial users, for 1 year from the date of purchase. No warranty is provided on batteries.



COMPLIES WITH:

- ASME A112.18.1 / CSA B125.1
- EPA WaterSense®

Delta reserves the right (1) to make changes in specifications and materials, and (2) to change or discontinue models, both without notice or obligation. Dimensions are for reference only. See current full-line price book or www.deltafaucet.com for finish options and product availability.

DSP-B-52672-15-BG Rev. A



55 E. 111th Street, Indianapolis, Indiana 46280
350 South Edgeware Road, St. Thomas, ON N5P 4L1
© 2015 Masco Corporation of Indiana



THE ORIGINAL™

0.8 GPF Single Flush Toilet Round Bowl with 12" Rough-In



THE ORIGINAL™ 0.8 GPF SINGLE FLUSH TOILET

Round Bowl with 12" Rough-In

FEATURES

- Quiet, powerful flush delivered with a patented Stealth® flush chamber and air transfer system
- Reliable standard Fluidmaster fill valve
- One flush thoroughly evacuates the bowl every time, eliminating double flushing
- Smooth, low friction ceramic surface helps achieve a clear bowl every time
- Two-piece toilet
- Stylish, inconspicuous and durable flush button
- No flapper to cause leakage
- Meets ADA Height Standards*

SPECIFICATIONS



Materials: Vitreous China **Finish Color:** White

Codes/Standards:

ASME A112.19.2/CSA B45.1

DOE - Energy Policy Act 1992

California Energy Commission (CEC)

MEASUREMENTS



*Pending final installation factors and seat attached. **LIMITED LIFETIME WARRANTY on vitreous china products. Toilet tank trim: fill valve and flush valve assembly and plumbing fittings are warranted for a period of fifteen (15) years to the purchaser from the date of purchase. Call Niagara Conservation* for complete warranty details.

CORPORATE HQ 1200 Lakeside Parkway, Suite 450, Flower Mound, Texas 75028 USA

© 2020 Niagara Conservation June 19, 2020 3:33 PM



BULK PACKAGING

N7716 Round Bowl

UPC Code 732291771641

Packaging Type Kraft Corrugated

Packaging Dimensions 15.5" W
16.5" H
27.5" D

Packaging Weight 50 lbs

Skid Quantity 18 or 12

N7714 Tank

UPC Code 732291771429

Packaging Type Kraft Corrugated

Packaging Dimensions 9.5" W
17" H
19" D

Packaging Weight 37 lbs

Skid Quantity 30

To place an order, please contact:

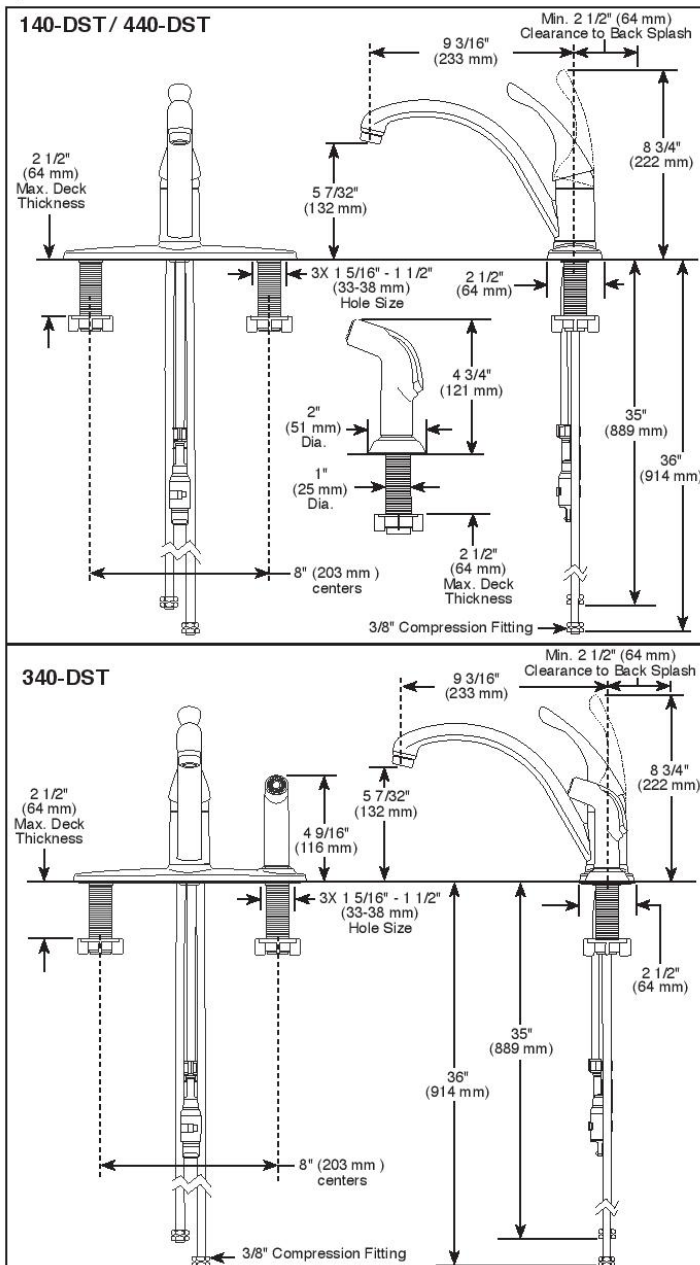
(p) 888.733.0197 (f) 682.200.6962 (e) info@niagaracorp.com

niagaracorp.com



Submitted Model No.: _____

Specific Features: _____



▲ Designate Proper Finish Suffix

Delta reserves the right (1) to make changes in specifications and materials, and (2) to change or discontinue models, both without notice or obligation. Dimensions are for reference only. See current full-line price book or www.deltafaucet.com for finish options and product availability.

DSP-K-140-DST Rev. G



KITCHEN FAUCETS

- Collins™ Series
- Single Handle Deck Mount

FEATURES:

- DIAMOND Seal® Technology

STANDARD SPECIFICATIONS:

- Maximum 1.8 gpm @ 60 PSI, 6.8 L/min @ 414 kPa
- "WE" models 1.5 gpm @ 60 PSI, 5.7 L/min @ 414 kPa
- Three or four hole mount (escutcheon included)
- Diamond coated ceramic cartridge
- 3/8" O.D. straight, staggered PEX supply lines
- Spout rotates 180°
- Red/blue indicator markings
- Models 340 and 440 series with spray attachment have anti-siphon device as integral part of faucet.
- Vegetable sprayer hose with matching finish sprayhead on models 340 and 440 series - 45" (1143mm) long hose.

WARRANTY

- Lifetime limited warranty on parts (other than electronic parts and batteries) and finishes; or, for commercial users, for 5 years from date of purchase.
- 5 year limited warranty on electronic parts (other than batteries); or, for commercial users, for 1 year from the date of purchase. No warranty is provided on batteries.

COMPLIES WITH:

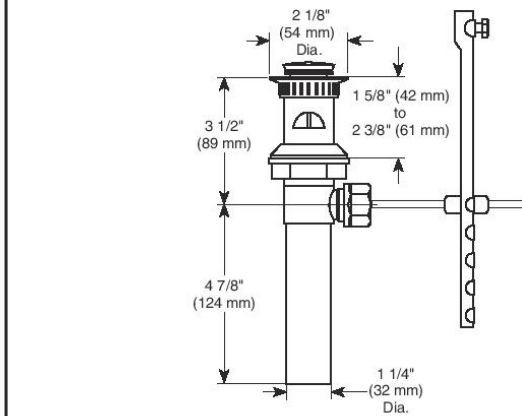
- ASME A112.18.1 / CSA B125.1
- ASME A112.18.6
- Indicates compliance to ICC/ANSI A117.1
- Verified compliant with .25% weighted average Pb content regulations.



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350 South Edgeware Road, St. Thomas, ON N5P 4L1
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Specific Features:




■ Foundations® Collection
■ Two Handle Centerset Deck Mount

- Maximum 1.5 gpm @ 60 psi, 5.7 L/min @ 414 kPa
- Max flow rate (ECO models only): 1.2 gpm @ 60 psi, 4.5 L/min @ 414 kPa
- Three hole mount
- Solid brass end valves and spout body
- Hot and cold stems are interchangeable
- 1/4 turn handle stops
- Control mechanism is a rotating cylinder type with stainless steel plate and 90° rotation, with replaceable non-metallic seats
- Models have drain with pop-up type fitting with plated flange and stopper
- RP76691 thick deck mounting kit adds 1 1/4" (25 mm) to maximum deck thickness

- Parts and Finish - Lifetime limited warranty; or for commercial purchasers, 10 years for multi-family residential (apartments and condominiums) and 5 years for all other commercial uses, in each case from the date of purchase.
- Electronic Parts and Batteries (if applicable) - 5 years from the date of purchase; or for commercial purchasers, 1 year from the date of purchase.

No warranty is provided on batteries.



- ASME A112.18.1 / CSA B125.1
- ASME A112.18.2 / CSA B125.2
-  Indicates compliance to ICC/ANSI A117.1
- EPA WaterSense®

DSP-L-B2511LF-PPU Rev. F

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FRIGIDAIRE

Top Freezer Refrigerator

FFHT1425V W/B/V

13.9 Cu. Ft. Top Freezer



Product Dimensions

Height	59-7/8"
Width	27-5/8"
Depth	25-1/4"
Depth (w/ Handle)	29-3/8"
Depth(w/ 90° Door Open)	54"

More Easy-To-Use Features

Ice Maker Ready

Enjoy the largest bucket capacity available without sacrificing valuable freezer space thanks to our easy-to-install, optional slim ice maker.

Energy Star Certified

Save money and maximize energy efficiency with this Energy Star-certified top-freezer refrigerator.

A.D.A. - Compliant¹

With accessible shelving, and controls that are positioned within arm's reach and allow one-hand operation, our top-freezer refrigerator is A.D.A.-Compliant.



Available in:



White
(W)



Black
(B)



Brushed
Steel
(V)

Signature Features

EvenTemp® Cooling System

Prevent warm spots and unwanted freezing with our EvenTemp® cooling system's optimized airflow that ensures a consistent temperature throughout your refrigerator.

Humidity-Controlled Crisper Drawer

Keep produce fresher longer, so you waste less and save money with our humidity-controlled crisper drawer.

Flexible Interior Storage System

Find a place for everything with our flexible interior storage options designed for busy families, including full-width glass shelving in the freezer and refrigerator, a sliding half-width deli drawer, and spacious door bins.

Auto-Close Doors

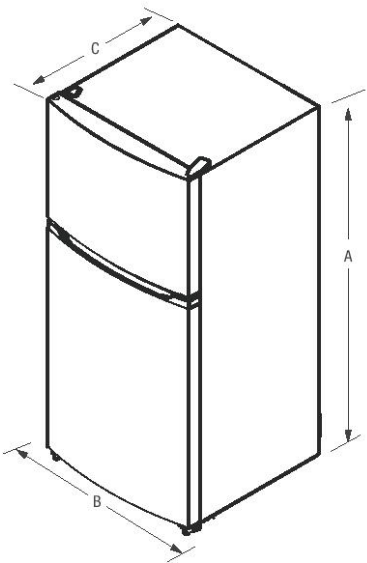
Avoid spoiled food and soupy ice cream with our auto-close doors, which ensure that your refrigerator and freezer are never left slightly open by mistake.

¹When properly installed, this model is A.D.A.-qualified based on the United States Access Board's A.D.A./A.B.A. Accessibility Guidelines and the Department of Justice's 2010 A.D.A. Standards for Accessible Design.

frigidaire.com

Features	
Door Design	Arc
Door Handle Design	Integrated
Cabinet Finish (Textured)	Color-Coordinated
Door Stops	Yes
Door Hinge Covers	Color-Coordinated
Door Reverse Option	Yes
Rollers - Front/Rear	Fixed
Refrigerator Features	
Interior Lighting	LED
Refrigerator Shelves	2 Adjustable Glass
Deli Drawer	Half-Width Sliding Deli Drawer
Crisper Drawers	1 Clear
Humidity Controls	1
Door Bins	2 White Gallon Door Bins, 1 White Half Gallon Door Bin
Freezer Features	
Door Bins	2 Fixed White
Freezer Shelves	1 Full-Width Glass
Factory Ice Maker w/ Large Ice Bin	Optional (PN #IM117)
Certifications	
A.D.A.-Compliant ¹	Yes
Specifications	
Total Capacity (Cu. Ft.)	13.9
Refrigerator Capacity (Cu. Ft.)	10.0
Freezer Capacity (Cu. Ft.)	3.9
Power Supply Connection Location	Right Bottom Rear
Water Inlet Connection Location	Left bottom Rear
Voltage Rating	120V / 60Hz
Minimum Circuit Required (Amps)	15
Shipping Weight (Approx.)	135 Lbs.

¹When properly installed, this model is A.D.A.-qualified based on the United States Access Board's A.D.A./A.B.A. Accessibility Guidelines and the Department of Justice's 2010 A.D.A. Standards for Accessible Design.
²For use on adequately wired 120V, dedicated circuit having 2-wire service with a separate ground wire. Appliance must be grounded for safe operation.



NOTE: For planning purposes only. Always consult local and national electric and plumbing codes. Refer to Product Installation Guide for detailed installation instructions on the web at frigidaire.com.



Product Dimensions	
A - Height (Incl. Hinges & Rollers)	60 1/2"
B - Width	27 5/8"
C - Depth (Incl. Door)	29 3/8"
Depth with Door Open 90°	54"

Accessories information available on the web at frigidaire.com

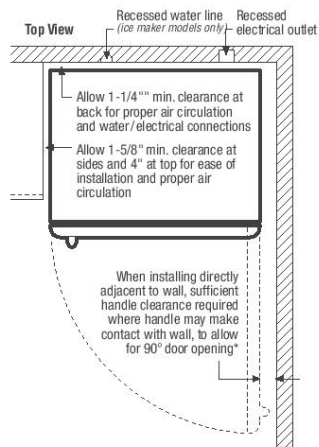
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CANADA • 5855 Terry Fox Way • Mississauga, ON L5V 3E4 • 1-800-265-8352 • frigidaire.ca

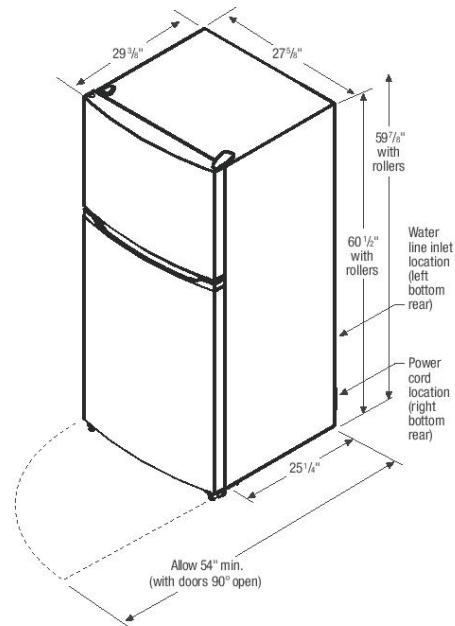
FFHT1425V 02/19

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Specifications subject to change.



*When installing refrigerator adjacent to wall, cabinet or other appliance that extends beyond front edge of unit, 24" minimum clearance recommended to allow for optimum 120° door swing, providing complete crisper access and removal. (Absolute 3" minimum clearance will ONLY allow for 90° door swing which will provide limited crisper access with restricted removal.)



Top Mount Refrigerator Specifications

- Product Shipping Weight (approx.) - 135 Lbs.
- An electrical supply with grounded three-prong receptacle is required. The power supply circuit must be installed in accordance with current edition of National Electrical Code (NECA 70) and local codes & ordinances.
- Voltage Rating - 120V / 60 Hz / 15 Amps
- Max Connected Load (kW Rating) @ 120 Volts = .36kW
- Max Amps @ 120 Volts = 3.0 Amps
- Always consult local and national electric & plumbing codes.
- Floor should be level surface of hard material, capable of supporting fully loaded refrigerator.
- To ensure optimum performance, do not install in areas where temperature drops below 55°F or rises above 110°F and avoid installing in direct sunlight or close proximity to range, dishwasher or other heat source.

- For proper ventilation, front grille MUST remain unobstructed.
- Recess electrical outlet when possible.
- Optional Ice Maker Kit (PN# IM117) available for installation in ice maker-ready models only.
- Water recess on rear wall recommended to prevent water line damage.
- Water Pressure - Cold water line must provide between 30 and 100 pounds per square inch (psi).
- Copper tubing with 1/4" O.D. recommended for water supply line with length equal to distance from rear of unit to household water supply line plus 7 additional feet. Optional Water Supply Installation Kits available.

Note: For planning purposes only. Refer to Product Installation Guide on the web at frigidaire.com for detailed instructions.

Optional Accessories

- Ice Maker Kit - (PN# IM117).

FRIGIDAIRE

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FFHT1425V 02/19

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Specifications subject to change.





55 dBA* Front Control Dishwasher

WDF330PAH



Stainless Steel
WDF330PAHS

Also available in:

-  White **WDF330PAHW**
-  Black **WDF330PAHB**

Capacity

Total Place Settings 13

General Features & Properties

Heavy Cycle

High Temperature Wash Option

Heated Dry Option

ENERGY STAR® Certified

Industry's Best Selling Dishwasher Brand†

Designed, Engineered and Assembled in the U.S.A. with American Pride

Electrical Details

Amps 10

Volts 120

Hz 60

Certifications

ENERGY STAR® Certified Yes

Technical Details

Dishwasher Type Built-in

Control Location Front

Control Type Push Button

Number of Wash Cycles 3

Number of Options 4

dBA* 55

Number of Racks 2

Tub Material Plastic

Wash System Filter

Wash System Type Removable Filter

Number of Wash Arms 2

Dimensions

Product Dimensions (H x W x D) 34-1/2" x 23-7/8" x 24-1/2"

Depth with Door Open 90° 49-1/2"

Reference Material

[Dimension Guide](#)

[Install Guide](#)

[Use & Care Guide](#)

[Energy Guide](#)

[Warranty](#)

Key Features & Benefits

1-Hour Wash Cycle

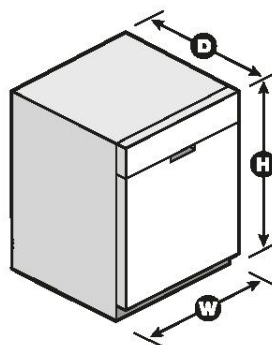
Clean dishes in half the time so your plates, pans and glasses are thoroughly cleaned up and taken care of in just an hour.**

Soil Sensor

Determines how dirty dishes are and adjusts the Normal cycle as needed to make sure dishes come out clean.

Normal Cycle

Use for normal amounts of food soil to clean up leftover messes from your day-to-day meals.



*Per IEC standards. **Compared to Normal cycle with lightly soiled loads. †Based on 12-month average of sales. TraQline 2018. NOTE: Dimensions are for planning purposes only. For complete details, see Installation Instructions packed with product. Specifications subject to change without notice. ©/™ © 2020. All rights reserved. Printed in the U.S.A. D200052XXA. WDF330PAHSPECSHEETV01.

NE63T811SS

SAMSUNG

Samsung Front Control Slide-in Electric Range

6.3 cu. ft. Capacity



Signature Features

Ready2Fit™ Guarantee

- If your Samsung Front Control Slide-In Range doesn't fit your 30" Freestanding Range cutout, enjoy \$100* on us to cover any countertop modification costs.

*Visit samsungpromotions.com/SlideInReady2Fit for details.

Fingerprint Resistant Finish

- Fingerprint resistant, for an everyday beautiful finish.

Flexible Cooktop

- Get to high heat quickly for searing meat or boiling water, or turn down to a simmer to make your favorite sauces. Has 5 heating elements, including 2 dual ring elements, so you can cook with small and large sized pots and pans.

Available Colors



Fingerprint Resistant
Stainless Steel (shown)



Fingerprint Resistant
Black Stainless Steel



Ready2Fit™ Guarantee



Fingerprint Resistant Finish

Features

- Ready2Fit™ Guarantee
- Fingerprint Resistant Finish
- Large Oven Capacity – 6.3 cu. ft.
- Glass Touch Controls
- Storage Drawer

- Flexible Cooktop:
Five Element Cooktop
 - Two Dual Elements (6"/9")
 - Two Single Elements (6")
 - Warming Center

Convenience

- Wi-Fi Connectivity
- Voice-Enabled
- Self & Steam Clean
- Hidden Bake Element
- Child Safety Lock
- Delay Start
- Auto Oven Light
- Kitchen Timer
- Sabbath Mode



Ready2Fit™



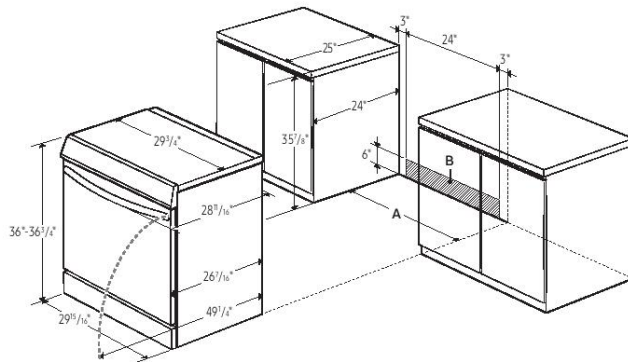
NE63T8111SS

SAMSUNG

Samsung Front Control Slide-in Electric Range

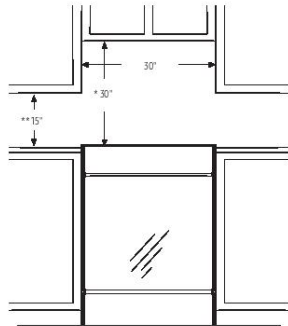
6.3 cu. ft. Capacity

Installation Specifications



A: Cabinet opening min 30"
B: Acceptable electrical outlet area

IMPORTANT: If your cabinets are over 36 3/4" high, you must install this range on a hard, heat resistant support that raises the surface of the range so that it is about even with the countertop.



* 30" minimum clearance between the top of the cooking surface and the bottom of an unprotected wood or metal cabinet; or 24" minimum when the bottom of the wood or metal cabinet is protected by not less than 1/4" of flame retardant millboard covered with not less than no.28 MSG sheet steel, 0.015" stainless steel, 0.024" aluminum, or 0.020" copper.

**15" minimum between the countertop and the adjacent cabinet bottom.

IMPORTANT: Consult with Installation Manual for detailed instructions before installing. All ranges must be installed with the Anti-Tip device that is included.

Power Source

240V/208V/60 Hz/40A

Electric Ceramic Cooktop

- Right Front: 6"/9" Dual Element, 3000 W
- Left Front: 6"/9" Dual Element, 3000 W
- Right Rear: 6", 1200 W
- Left Rear: 6", 1200 W
- Center: 7" Warming Center

Oven

- Capacity: 6.3 cu. ft.
- Hidden Bake Element
- Bake
- Variable Broil: Low/High
- Bread Proof

Warranty

One (1) Year Parts and Labor

Product Dimensions & Weight (WxHxD)

Oven Interior Dimensions:

24 13/16" x 22 7/16" x 19 3/4"

Outside Net Dimensions:

29 15/16" x 36 - 36 3/4" (Adjustable) x 28 11/16"

Weight: 166 lbs

Shipping Dimensions & Weight (WxHxD)

Dimensions:

33 1/16" x 41 3/4" x 30 5/16"

Weight: 189 lbs

Color

Fingerprint Resistant

Stainless Steel

Fingerprint Resistant

Black Stainless Steel

Model

NE63T8111SS

NE63T8111SG

UPC Code

887276409009

887276408996



Actual color may vary. Design, specifications, and color availability are subject to change without notice. Non-metric weights and measurements are approximate.

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0.7 CU. FT. MICROWAVE

Product Features

- 0.7 CU FT
- 700 WATTS
- LED DISPLAY
- DIGITAL KITCHEN TIMER
- 6 ONE TOUCH COOKING MENUS
- POWER LEVELS: 10
- AUTO DEFROST
- EXPRESS COOKING
- DIGITAL CLOCK REMOVABLE GLASS
TURNTABLE
- COLORS: BLACK

Model: RMW733-BLACK

[illegible]

Domestic Cost: \$

FOB China: \$

Comments:



CURTIS INTERNATIONAL LTD.
www.curtisint.com

WF45R6300AV

SAMSUNG

Samsung Smart Front Load Washer with Super Speed

4.5 cu. ft. Capacity DOE



Signature Features

Super Speed

- Uses advanced cleaning technologies to wash a full load of laundry in just 30 minutes¹, without sacrificing cleaning performance.

Bixby Enabled


- AI-powered laundry care helps you choose the best cycle option and notifies you on your smartphone² when the cycle is complete.

Steam

- Powerful stain removal without pretreatment, while still gentle on your clothing.

Available Colors




Bixby Enabled 



Steam

Features

- Bixby Enabled 
- Super Speed
- Steam
- VRT Plus™ Technology
- Swirl+ Drum Design
- Self Clean+
- Closet-Depth Fit³
- Stackability
- Internal Water Heater
- 1200 RPM Maximum Spin Speed
- Direct Drive Motor
- 12 Preset Washing Cycles
- 9 Additional Washing Options

- 5 Temperature Levels
- Crystal Blue Door
- LED Display: Ice Blue
- 24-Hour Delay End

Convenience

- Child Lock
- Delay End
- Dispenser Trays: Main Wash, Softener, Bleach



Rating

- ENERGY STAR®-rated
- CEE Tier 2
- IMEF = 2.92
- IWF = 2.9

¹Based on using Super Speed on a normal cycle with an 8lb load.

²The Samsung SmartThings application is required and is available on Android and iOS devices. A Wi-Fi connection is required. User will be solely responsible for any consequence(s) that may result, including but not limited to any damage or harm caused by incorrect information provided by the user. The recommended washing cycle is only based on time and may not be appropriate based on the type of fabrics or stain level of the articles being washed.

³Designed to fit a 40" installation depth.

⁴ADA Compliant when using a Samsung 27" wide riser (WE272NV or WE272NW).

WF45R6300AV

SAMSUNG

Samsung Smart Front Load Washer with Super Speed

4.5 cu. ft. Capacity DOE

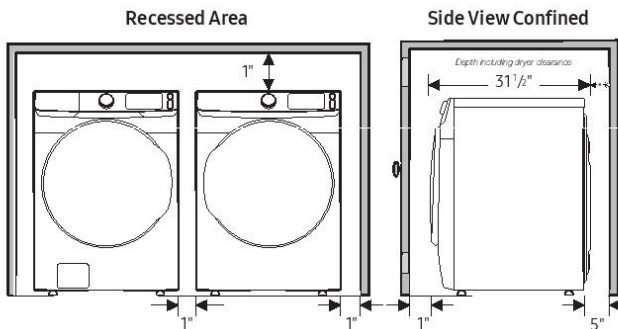
Installation Specifications

If the washer and dryer are installed together or the dryer alone, the closet front must have two unobstructed air openings for a combined minimum total area of 72-inch² (see stacked build below). Your washer alone does not require a specific air opening.

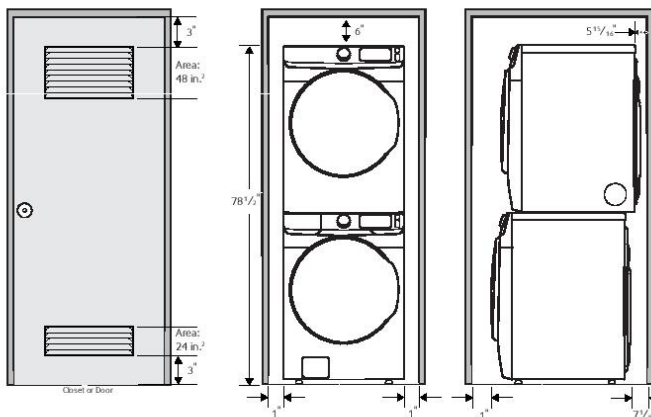
*Required spacing (External exhaust elbow may require additional space.)

1. Alcove or closet installation

Minimum Clearance for Closet and Alcove Installations:

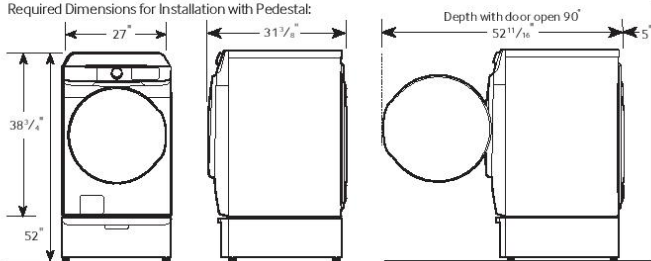


2. With stacked washer and dryer



Dimensions

Required Dimensions for Installation with Pedestal:



Actual color may vary. Design, specifications, and color availability are subject to change without notice. Non-metric weights and measurements are approximate.

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12 Preset Washing Cycles:

Normal, Heavy Duty, Bedding, Quick Wash, Permanent Press, Delicates, Whites, Sanitize, Activewear, Rinse and Spin, Self Clean+, Downloaded

9 Additional Washing Options:

Presoak, Steam, Delay End, Smart Control, Super Speed, Alarm Off, Child Lock, Smart Care, Spin Only

5 Temperature Levels:

Hot, Warmer, Warm, Cool, Cold

5 Spin Speeds:

High, Medium High, Medium, Low, No Spin

5 Soil Levels:

Heavy, Medium Heavy, Normal, Medium Low, Light

Dispenser Trays:

Main Wash, Softener, Bleach

Warranty

One (1) Year Parts and Labor

Three (3) Years Stainless Steel Drum (Part Only)

Ten (10) Years Direct Drive Motor (Part Only)

Product Dimensions & Weight (WxHxD)

Dimensions: 27" x 38 3/4" x 31 3/8"

Weight: 201 lbs

Shipping Dimensions & Weight (WxHxD)

Dimensions: 29 3/8" x 42 3/8" x 34 1/8"

Weight: 205 lbs

Color	Model #	UPC Code
Fingerprint Resistant Black Stainless Steel	WF45R6300AV	887276299488
Champagne	WF45R6300AC	887276331461
White	WF45R6300AW	887276299495

Matching Dryer (Electric/Gas)

Fingerprint Resistant Black Stainless Steel	DVE45R6300V	887276300467
Champagne	DVE45R6300C	887276331638
White	DVE45R6300W	887276300474

Fingerprint Resistant Black Stainless Steel	DVG45R6300V	887276300504
Champagne	DVG45R6300C	887276331645
White	DVG45R6300W	887276300511

Pedestal

Fingerprint Resistant Black Stainless Steel	WE402NV	887276310145
Champagne	WE402NC	887276310121
White	WE402NW	887276310152

Accessories

Stacking Kit	SKK-7A	887276146423
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DVE45R6300V

SAMSUNG

Samsung Smart Front Load Electric Dryer with Steam Sanitize+

7.5 cu. ft. Capacity DOE



Signature Features

Bixby Enabled

- Wi-Fi connected so you can remotely start or stop your cycle, schedule laundry on your time, receive end of cycle alerts, and more right from your smartphone.¹

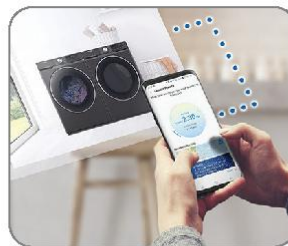
Steam Sanitize+

- The Steam Sanitize+ cycle removes 99.9% of germs and bacteria, over 95% of pollen, and kills 100% of dust mites². Multi-Steam Technology steams away wrinkles, odors, and static.

Sensor Dry

- Automatically optimizes the time and temperature of your drying cycle to protect your clothes from heat damage, while avoiding excess energy use.

Available Colors



Bixby Enabled



Steam Sanitize+

Features

- Bixby Enabled
- Steam Sanitize+
- Sensor Dry
- Vent Sensor
- Interior Drum Light
- 12 Preset Drying Cycles
- 10 Additional Drying Options
- 5 Temperature Levels
- 4-Way Venting
- Dual Heaters
- Reversible Crystal Blue Door
- LED Display: Ice Blue

Convenience

- Child Lock
- Lint Filter Indicator



ADA Compliant³

Rating

ENERGY STAR®-rated
607 kWh/yr

¹The Samsung SmartThings application is required and is available on Android and iOS devices. A Wi-Fi connection is required. User will be solely responsible for any consequence(s) that may result, including but not limited to any damage or harm caused by incorrect information provided by the user. Only monitoring is allowed for Gas dryer for safety reasons.

²Based on internal testing and independently verified by Intertek. Individual results may vary.

³ADA Compliant when using a Samsung 27" wide riser (WE272NV or WE272NW).

DVE45R6300V

SAMSUNG

Samsung Smart Front Load Electric Dryer with Steam Sanitize+

7.5 cu. ft. Capacity DOE

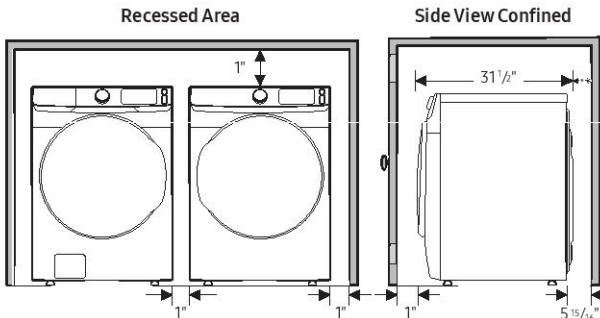
Installation Specifications

If the washer and dryer are installed together or the dryer alone, the closet front must have two unobstructed air openings for a combined minimum total area of 72-inch² (see stacked build below). Your washer alone does not require a specific air opening.

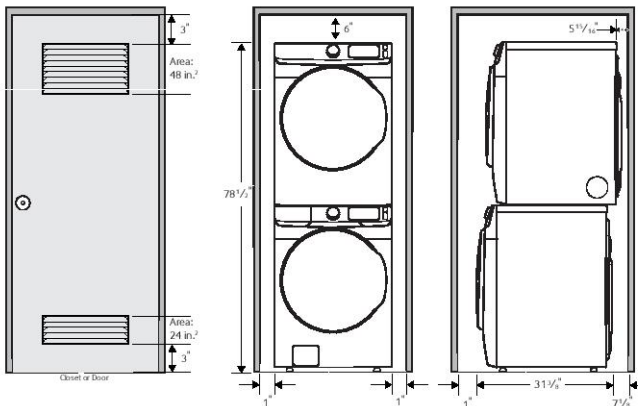
*Required spacing (External exhaust elbow may require additional space.)

1. Alcove or closet installation

Minimum Clearance for Closet and Alcove Installations:

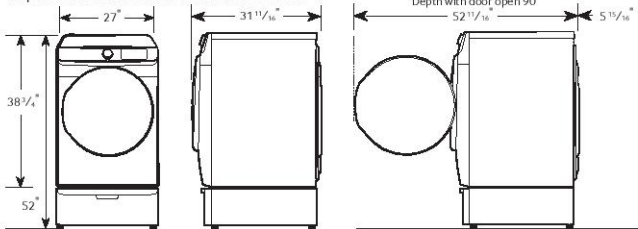


2. With stacked washer and dryer



Dimensions

Required Dimensions for Installation with Pedestal:



4-Way Venting

12 Preset Drying Cycles:

Refresh, Steam Sanitize+, Normal, Heavy Duty, Permanent Press, Active Wear, Bedding, Delicates, Time Dry, Air Fluff, Quick Dry, Downloaded

10 Additional Drying Options:

Damp Alert, Wrinkle Prevent, Smart Control, Adjust Time (Up), Adjust Time (Down), Eco Dry, Drum Light, Child Lock, Smart Care, Alarm Off

5 Temperature Levels:

High, Medium High, Medium, Medium Low, Low

5 Dry Levels:

More Dry, Normal-More Dry, Normal Dry, Normal-Less Dry, Less Dry

Warranty

One (1) Year Parts and Labor

Product Dimensions & Weight (WxHxD)

Dimensions: 27" x 38 3/4" x 31 1/2"

Weight: 123 lbs

Shipping Dimensions & Weight (WxHxD)

Dimensions: 29 3/8" x 42 9/16" x 33 1/2"

Weight: 130 lbs

Electric	Model #	UPC Code
Fingerprint Resistant Black Stainless Steel	DVE45R6300V	887276300467
Champagne	DVE45R6300C	887276331638
White	DVE45R6300W	887276300474

Gas	Model #	UPC Code
Fingerprint Resistant Black Stainless Steel	DVG45R6300V	887276300504
Champagne	DVG45R6300C	887276331645
White	DVG45R6300W	887276300511

Matching Washer

Fingerprint Resistant Black Stainless Steel	WF45R6300AV	887276299488
Champagne	WF45R6300AC	887276331461
White	WF45R6300AW	887276299495

Pedestal

Fingerprint Resistant Black Stainless Steel	WE402NV	887276310145
Champagne	WE402NC	887276310121
White	WE402NW	887276310152

Accessories

Stacking Kit	SKK-8K	887276344034
Vent Kit	DV-2A	887276146416

Actual color may vary. Design, specifications, and color availability are subject to change without notice. Non-metric weights and measurements are approximate.

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APPENDIX V: BUDGET & IBOM

This contains the final iBOM for the theoretical build as well as the actual budget for our project. Because this was a virtual deliverable, we had no costs associated with the production of our project. Similarly, we have no item or part numbers or vendors.

Alice Harris Community Residences Indented Bill of Material (iBOM)

Assembly Level	Part Number	Description	Qty	Cost	Ttl Cost	Source	More Info
		Lvl0 Lvl1 Lvl2 Lvl3 Lvl4					
0		Final Building					
1		Building Envelope					
2		Insulation					
3		Rigid Insulation (Quantity in packs of	85	\$56.08	\$4,766.80	Amvic	AMDKIT001
3		Cellulose (Quantity in pallet of 36 ba	267	\$455.00	\$121,485.00	GreenFiber	INS765LD
2		Structure					
3		Plaster Board	TBD		#VALUE!		
3		Studs	TBD		#VALUE!		
3		Plywood	TBD		#VALUE!		
1		HVAC					
2		Fan Coil Units	24	\$2,000.00	\$48,000.00	LG	
2		DOAS	4	\$1,500.00	\$6,000.00	LG	
2		Condensing Units	2	\$1,000.00	\$2,000.00	LG	
2		Branch Controllers	4	\$700.00	\$2,800.00	LG	
2		Pumps	12	\$100.00	\$1,200.00	LG	
2		Refrigerant Piping	720	\$20.00	\$14,400.00	Ferguson	
2		Ductwork	720	\$55.00	\$39,600.00	Carrier	
1		Solar Power System	46500	\$2.75	\$127,875.00		Qty is system wattage, cost is avg system cost per watt in LA county
1		Plumbing					
2		Fixtures					
3		Showerheads	12	\$19.99	\$239.88	Delta	56272-15-BG
3		Toilets	12	\$144.13	\$1,729.56	Niagara	N7716
3		Faucets					
4		Kitchen Sink Faucet	12	\$133.81	\$1,605.72	Delta	440-DST
4		Bathroom Sink Faucet	12	\$39.00	\$468.00	Delta	B2511LF-PPU
4		Bathtub Faucet	12	\$19.41	\$232.92	American Std.	8888026-002
2		Piping	TBD		#VALUE!		Dependent on Arch.
1		Appliances					
2		Kitchen					
3		Refrigerator	12	\$674.00	\$8,088.00	Frigidaire	model FFHT1425VV
3		Dishwasher	12	\$429.00	\$5,148.00	Whirlpool	model WDF330PAHB
3		Electric Range	12	\$848.00	\$10,176.00	Samsung	model NE63T8111SS
3		Microwave	12	\$50.94	\$611.28	RCA	model RMW733
2		Laundry Room					
3		Washer	6	\$798.00	\$4,788.00	Samsung	model WF45R6300AV
3		Dryer	6	\$798.00	\$4,788.00	Samsung	model DVE45R6300V
Total Parts			48338	(Not Accurate)			

Item	Purchaser	Procurement Process	Cost
Application Fee	Team	Purchased using Cal Poly pro card from the Solar Decathlon portal	\$100
Revit	---	Available through Cal Poly virtual labs or student access	\$0
Revit Family Files for LG Components	---	Downloaded from LG website	\$0
Revit Architecture File	---	Provided by the architecture side of the team	\$0
Floorplan PDF	---	Provided by the architecture side of the team	\$0
Design Builder	---	Available through Cal Poly remote desktop	\$0
Trace 700	---	Available through Cal Poly remote desktop	\$0
Helioscope	---	Available in free trial	\$0
Opaque	---	Available through Cal Poly	\$0
Total Cost			\$100

APPENDIX W: RISK ASSESSMENT

F46

2/18/2021

designsafe Report

Application: F46

Analyst Name(s):

Description:

Company:

Product Identifier:

Facility Location:

Assessment Type: Detailed

Limits:

Sources:

Risk Scoring System: ANSI B11.0 (TR3) Two Factor

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment		Risk Reduction Methods /Control System	Final Assessment		Status / Responsible /Comments /Reference
			Severity Probability	Risk Level		Severity Probability	Risk Level	
1-1-1	Engineer walk / investigate site	slips / trips / falls : slip	Minor Likely	Low		Minor		
1-1-2	Engineer walk / investigate site	slips / trips / falls : trip	Minor Likely	Low		Minor		
1-1-3	Engineer walk / investigate site	slips / trips / falls : fall hazard from elevated work	Moderate Likely	Medium		Moderate		
1-2-1	Engineer communicate with others	construction site : scheduling / work sequence conflict	Minor Likely	Low		Minor		
1-3-1	Engineer advise / direct / support others	construction site : scheduling / work sequence conflict	Minor Likely	Low		Minor		
1-3-2	Engineer advise / direct / support others	construction site : housekeeping	Minor Unlikely	Negligible		Minor		
2-1-1	Supervisor / Foreman supervise personnel	construction site : scheduling / work sequence conflict	Minor Likely	Low		Minor		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment		Risk Reduction Methods / Control System	Final Assessment		Status / Responsible / Comments / Reference
			Severity Probability	Risk Level		Severity Probability	Risk Level	
2-1-2	Supervisor / Foreman supervise personnel	construction site : too many workers in one area	Minor Very Likely	Medium		Minor		
2-2-1	Supervisor / Foreman walk / investigate site	slips / trips / falls : slip	Minor Likely	Low		Minor		
2-2-2	Supervisor / Foreman walk / investigate site	slips / trips / falls : trip	Minor Likely	Low		Minor		
2-2-3	Supervisor / Foreman walk / investigate site	slips / trips / falls : fall hazard from elevated work	Moderate Likely	Medium		Moderate		
3-1-1	Laborer lift / lower materials	slips / trips / falls : slip	Minor Likely	Low		Minor		
3-1-2	Laborer lift / lower materials	slips / trips / falls : trip	Minor Likely	Low		Minor		
3-1-3	Laborer lift / lower materials	slips / trips / falls : fall hazard from elevated work	Moderate Likely	Medium		Moderate		
3-1-4	Laborer lift / lower materials	ergonomics / human factors : Moderate repetition	Likely	Medium		Moderate		
3-1-5	Laborer lift / lower materials	ergonomics / human factors : Moderate lifting / bending / twisting	Likely	Medium		Moderate		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment		Risk Reduction Methods /Control System	Final Assessment		Status / Responsible /Comments /Reference
			Severity Probability	Risk Level		Severity Probability	Risk Level	
3-1-6	Laborer lift / lower materials	material handling : excessive weight	Moderate Likely	Medium		Moderate		
3-1-7	Laborer lift / lower materials	ventilation / confined space : confined space	Minor Likely	Low		Minor		
3-2-1	Laborer setup / remove scaffolds	mechanical : pinch point	Moderate Remote	Negligible		Moderate		
3-2-2	Laborer setup / remove scaffolds	mechanical : head bump on overhead objects	Minor Likely	Low		Minor		
3-2-3	Laborer setup / remove scaffolds	slips / trips / falls : fall hazard from elevated work	Serious Likely	High	OSHA training for all laborers and non-slip shoes	Serious		
3-2-4	Laborer setup / remove scaffolds	construction site : too many workers in one area	Minor Very Likely	Medium		Minor		
3-3-1	Laborer clean tools / equipment	mechanical : drawing-in / trapping / entanglement	Serious Remote	Low		Serious		
3-3-2	Laborer clean tools / equipment	mechanical : pinch point	Moderate Unlikely	Low		Moderate		
3-3-3	Laborer clean tools / equipment	environmental / industrial hygiene : irritants	Moderate Unlikely	Low		Moderate		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment		Risk Reduction Methods /Control System	Final Assessment		Status / Responsible /Comments /Reference
			Severity Probability	Risk Level		Severity Probability	Risk Level	
3-4-1	Laborer load / unload trucks	slips / trips / falls : slip	Minor Likely	Low		Minor		
3-4-2	Laborer load / unload trucks	slips / trips / falls : trip	Minor Likely	Low		Minor		
3-4-3	Laborer load / unload trucks	slips / trips / falls : fall hazard from elevated work	Moderate Likely	Medium		Moderate		
3-4-4	Laborer load / unload trucks	ergonomics / human factors : Moderate repetition	Moderate Likely	Medium		Moderate		
3-4-5	Laborer load / unload trucks	ergonomics / human factors : Moderate duration	Moderate Likely	Medium		Moderate		
3-4-6	Laborer load / unload trucks	ergonomics / human factors : Moderate lifting / bending / twisting	Moderate Likely	Medium		Moderate		
3-4-7	Laborer load / unload trucks	material handling : movement to / from storage	Moderate Likely	Medium		Moderate		
3-4-8	Laborer load / unload trucks	material handling : excessive weight	Moderate Likely	Medium		Moderate		
3-4-9	Laborer load / unload trucks	material handling : motor vehicle movement	Catastrophic Remote	Low		Catastrophic		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment		Risk Reduction Methods /Control System	Final Assessment		Status / Responsible /Comments /Reference
			Severity Probability	Risk Level		Severity Probability	Risk Level	
4-1-1	Plumber / Pipefitter cut pipe	mechanical : cutting / severing	Serious Unlikely	Medium		Serious		
4-1-2	Plumber / Pipefitter cut pipe	mechanical : pinch point	Moderate Remote	Negligible		Moderate		
4-1-3	Plumber / Pipefitter cut pipe	mechanical : stabbing / puncture	Serious Unlikely	Medium		Serious		
4-2-1	Plumber / Pipefitter assemble / install valves / pipe fittings / pipes	mechanical : pinch point	Moderate Remote	Negligible		Moderate		
4-2-2	Plumber / Pipefitter assemble / install valves / pipe fittings / pipes	confined spaces : confined spaces	Minor Likely	Low		Minor		
4-2-3	Plumber / Pipefitter assemble / install valves / pipe fittings / pipes	ventilation / confined space : lack of fresh air	Moderate Unlikely	Low		Moderate		
4-2-4	Plumber / Pipefitter assemble / install valves / pipe fittings / pipes	ventilation / confined space : air contaminants	Serious Unlikely	Medium		Serious		
4-3-1	Plumber / Pipefitter install brackets / holders	mechanical : pinch point	Moderate Remote	Negligible		Moderate		
4-3-2	Plumber / Pipefitter install brackets / holders	ventilation / confined space : confined space	Minor Likely	Low		Minor		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment		Risk Reduction Methods / Control System	Final Assessment		Status / Responsible / Comments / Reference
			Severity Probability	Risk Level		Severity Probability	Risk Level	
4-3-3	Plumber / Pipefitter install brackets / holders	ventilation / confined space : lack of fresh air	Moderate Unlikely	Low		Moderate		
4-3-4	Plumber / Pipefitter install brackets / holders	ventilation / confined space : air contaminants	Serious Unlikely	Medium		Serious		
5-1-1	Heating & A/C Installer / Servicer install compressor / condenser units	fluid / pressure : high pressure coolant	Serious Unlikely	Medium		Serious		
5-1-2	Heating & A/C Installer / Servicer install compressor / condenser units	fluid / pressure : hydraulics rupture	Serious Unlikely	Medium		Serious		
5-1-3	Heating & A/C Installer / Servicer install compressor / condenser units	fluid / pressure : pneumatics rupture	Serious Unlikely	Medium		Serious		
5-1-4	Heating & A/C Installer / Servicer install compressor / condenser units	fluid / pressure : fluid leakage / ejection	Moderate Likely	Medium		Moderate		
5-2-1	Heating & A/C Installer / Servicer install evaporator unit	fluid / pressure : high pressure coolant	Serious Unlikely	Medium		Serious		
5-2-2	Heating & A/C Installer / Servicer install evaporator unit	fluid / pressure : hydraulics rupture	Serious Unlikely	Medium		Serious		
5-2-3	Heating & A/C Installer / Servicer install evaporator unit	fluid / pressure : pneumatics rupture	Serious Unlikely	Medium		Serious		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment		Risk Reduction Methods /Control System	Final Assessment		Status / Responsible /Comments /Reference
			Severity Probability	Risk Level		Severity Probability	Risk Level	
5-2-4	Heating & A/C Installer / Servicer install evaporator unit	fluid / pressure : fluid leakage / ejection	Moderate Likely	Medium		Moderate		
5-3-1	Heating & A/C Installer / Servicer install expansion / discharge valves in circuit	fluid / pressure : high pressure coolant	Serious Unlikely	Medium		Serious		
5-3-2	Heating & A/C Installer / Servicer install expansion / discharge valves in circuit	fluid / pressure : hydraulics rupture	Serious Unlikely	Medium		Serious		
5-3-3	Heating & A/C Installer / Servicer install expansion / discharge valves in circuit	fluid / pressure : pneumatics rupture	Serious Unlikely	Medium		Serious		
5-3-4	Heating & A/C Installer / Servicer install expansion / discharge valves in circuit	fluid / pressure : fluid leakage / ejection	Moderate Likely	Medium		Moderate		
5-3-5	Heating & A/C Installer / Servicer install expansion / discharge valves in circuit	fluid / pressure : liquid / vapor hazards	Serious Unlikely	Medium		Serious		
5-4-1	Heating & A/C Installer / Servicer inject refrigerant into compressor	fluid / pressure : high pressure coolant	Serious Unlikely	Medium		Serious		
5-4-2	Heating & A/C Installer / Servicer inject refrigerant into compressor	fluid / pressure : hydraulics rupture	Serious Unlikely	Medium		Serious		
5-4-3	Heating & A/C Installer / Servicer inject refrigerant into compressor	fluid / pressure : fluid leakage / ejection	Serious Unlikely	Medium		Serious		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment		Risk Reduction Methods /Control System	Final Assessment		Status / Responsible /Comments /Reference
			Severity Probability	Risk Level		Severity Probability	Risk Level	
5-4-4	Heating & A/C Installer / Servicer inject refrigerant into compressor	fluid / pressure : liquid / vapor hazards	Serious Unlikely	Medium		Serious		
5-4-5	Heating & A/C Installer / Servicer inject refrigerant into compressor	chemical : reaction to / with irritant chemicals	Moderate Unlikely	Low		Moderate		
5-4-6	Heating & A/C Installer / Servicer inject refrigerant into compressor	chemical : skin exposed to toxic chemical	Serious Unlikely	Medium		Serious		
5-4-7	Heating & A/C Installer / Servicer inject refrigerant into compressor	chemical : chemical emissions	Serious Unlikely	Medium		Serious		
5-5-1	Heating & A/C Installer / Servicer install insulation	mechanical : cutting / severing	Serious Remote	Low		Serious		
5-5-2	Heating & A/C Installer / Servicer install insulation	mechanical : pinch point	Moderate Remote	Negligible		Moderate		
5-5-3	Heating & A/C Installer / Servicer install insulation	mechanical : head bump on overhead objects	Minor Likely	Low		Minor		
5-5-4	Heating & A/C Installer / Servicer install insulation	ventilation / confined space : confined space	Minor Likely	Low		Minor		
5-5-5	Heating & A/C Installer / Servicer install insulation	ventilation / confined space : lack of fresh air	Moderate Unlikely	Low		Moderate		

APPENDIX X: TEST PROCEDURES

Test Procedure

Team: F46 Solar Decathlon

Team Member: Khanh Fleshman

Test Name: HVAC Design Load and Energy Consumption

Purpose: The purpose of this test is to determine both the design heating/cooling load and yearly energy consumption of the HVAC system.

Scope: This test uses building energy performance modeling software to calculate important energy usage characteristics regarding the mechanical systems of the building.

Equipment:

Laptop

Trace 700 Software

Design Builder Software

Hazards: N/A – computational analysis

PPE Requirements: N/A – computational analysis

Facility: Individual workspace

Procedure:

Design Builder

- 1) Specify occupant density
- 2) Specify construction materials (glazing, fenestration, wall, insulation, roof, foundations, etc.)
- 3) Specify geographic location
- 4) Specify HVAC system (VRF with DOAS and HRV)
- 5) Zone spaces by room
- 6) Specify activity level and equipment loads of each room
- 7) Run heating/cooling simulations
- 8) Run year long simulation

Trace 700

- 9) Make construction, internal load, airflow, and thermostat templates
- 10) Specify weather data
- 11) Create rooms based on templates
- 12) Create HVAC system (ventilation)
- 13) Assign rooms to system
- 14) Create heating/cooling plant using VRF templates
- 15) Assign rooms to plants
- 16) Specify occupancy schedule

17) Run simulation

Results:

The results from this test are more to find energy usage of the building, compare the results from both software, and compare the results to a benchmark using case studies. This test will yield:

- Peak cooling load
- Peak heating load
- Yearly cooling energy usage
- Yearly heating energy usage
- DHW energy usage

Test Date(s): 3/03 – 4/29

Test Results:

Parameter	Design Builder	Trace	Benchmark
Peak cooling load			
Peak heating load			
Yearly cooling energy usage			
Yearly heating energy usage			
DHW energy usage			

Performed by: Ashley Kim and Erich Fenczik Warnock

Test Procedure

Team: F46 Solar Decathlon

Team Member: Khanh Fleshman

Test Name: Water Consumption Estimate

Purpose: This test determines the water consumption for the entire building.

Scope: This test will allow us to size water heating equipment (heat pump water heaters, storage tanks, etc), estimate utility costs for residents, and benchmark our building's performance with regard to water consumption.

Equipment:

Laptop

Excel

ASHRAE Handbook of Applications

Hazards: N/A Computational Analysis

PPE Requirements: N/A Computational Analysis

Facility: Team Members' workspace

Procedure:

- 1) Find number of water fixtures for entire building (faucets, showers, washing machines, toilets, dishwashers, etc.)
- 2) Find water consumption per fixture from ASHRAE Handbook of Applications
- 3) Create Excel to multiply number of fixtures times individual water consumption of each to find maximum possible demand
- 4) Multiply by demand factor to find probable demand
- 5) Multiply by storage capacity factor to find storage tank capacity

Results:

Total Water Consumption per Capita < 21 gal/person

Test Date(s): 03/15 – 03/30

Test Results:

Fixture Type	# of Fixtures	Consumption/Fixture	Total Consumption
Showerhead			
Toilets			
Bathroom Sink			
Kitchen Sink			
Dishwasher			
Clothes Washer			

Performed By: Khanh Fleshman and Ian MacLean

Test Procedure

Test Name: Determining Optimum Solar Layout (Tilt and Number of Rows)

Purpose: The purpose of this test is to determine the optimum tilt angle and number of solar panel rows to maximize annual energy output.

Scope: The test is for the solar PV energy production system. It will guide our design, making the system as efficient as possible with the given roof space.

Equipment/Software:

Laptop

Microsoft Excel

Helioscope

Hazards:

N/A (computational only)

PPE Requirements:

N/A (computational only)

Facility:

Computer

Procedure: (List number steps of how to run the test, can include sketches and/or pictures):

- 1) Open architectural model (made prior to testing) in Helioscope design editor.

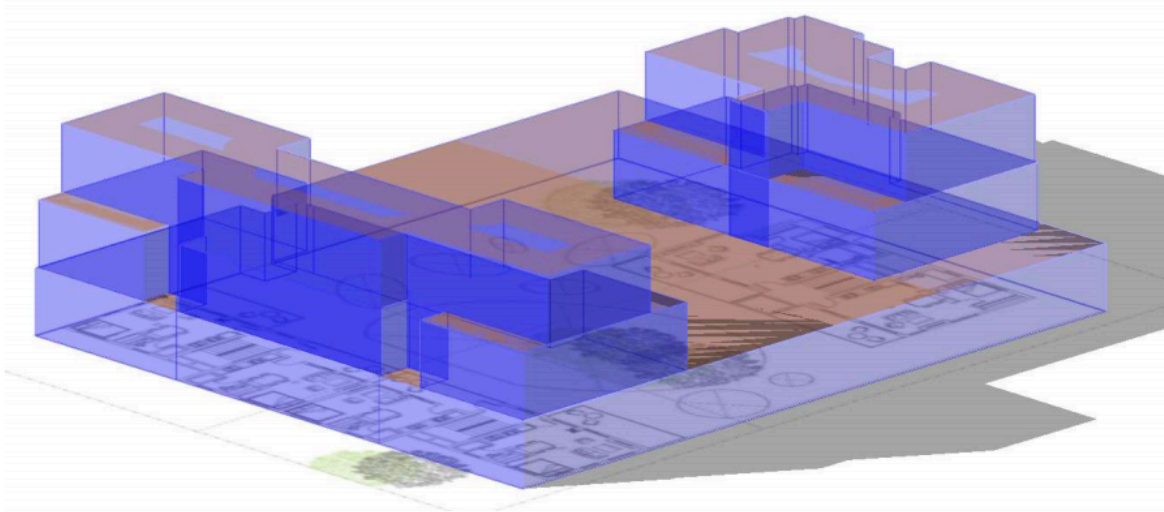


Figure 1: Architectural Model (no panels)

- 2) Add panels by clicking on one of the rooftops and editing the tilt angle and row spacing in the menu on the left side of the screen.

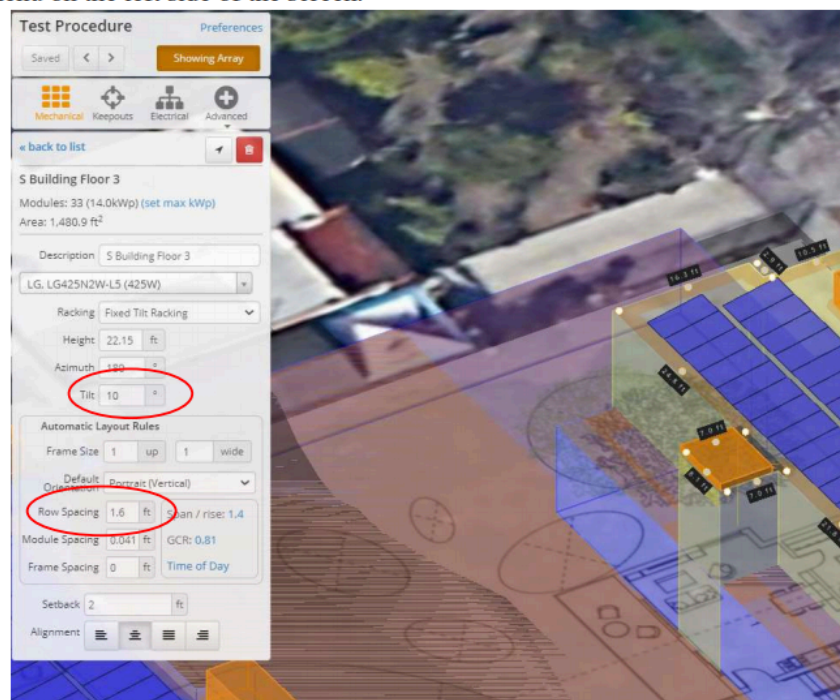


Figure 2: Edit menu

- 3) Adjust the row spacing value until exactly 2 rows of panels fit on the roof space. Increase the row spacing value to maximize the spacing between the two rows (One row is as North as possible and one row is as South as possible)

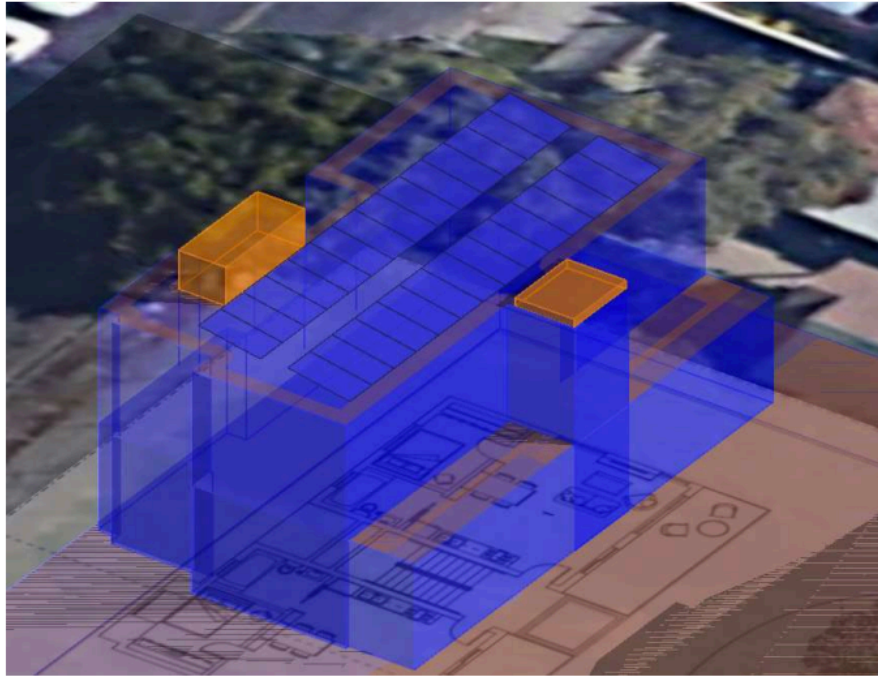


Figure 3: Roof with 2 Rows

- 4) Set tilt to 0° , Click the “Advanced” Tab and then “Shading” in the edit menu. Then click “Calculate Shading,” making sure the “Ignore row-to-row shading” button is unchecked.
- 5) Find the resulting Annual Energy (circled in Figure 4) and record this value along with the number of rows used and the tilt angle.



Figure 4: Shading Calculation menu

- 6) Repeat Steps 4-5 for tilt angles of 10, 20, 30, and 40.
- 7) Repeat Steps 3-6 for 3 rows and 4 rows of panels on the roof.
- 8) Make a table in excel with columns titled: # of rows, tilt angle, and annual energy production.

Trial	# of Rows	Tilt Angle	Annual Energy Production
		[degrees]	[MWh]
1	2	10	
2	2	20	
3	2	30	
4	2	40	
5	3	10	
6	3	20	
7	3	30	
8	3	40	
9	4	10	
10	4	20	
11	4	30	
12	4	40	

Table 1: Data Table for Test Procedure

- 9) Plot Annual Energy Production Vs. Tilt Angle for 2 rows, 3 rows, and 4 rows. (1 plot, 3 datasets)

Results:

Data showing which layout will generate the most power over a year for this specific rooftop and geographical location.

Test Date(s): 3/1 – 3/30

Test Results:

Performed By: Ian MacLean

HERS Test Procedure

Test Name: HERS rating

Purpose: *To determine if our building is net-zero*

Scope: The test is used to model our buildings energy

Equipment: REM/RATE software

Hazards: N/A

PPE Requirements: N/A

Facility: computer

Procedure: (List number steps of how to run the test, can include sketches and/or pictures):

- 1) determine which room in building to test: 2-bedroom 700 SF
- 2) insert specs about the HVAC system: 18K 12 SEER air 6.8 hspf air-source heat pump, infiltration of 0.30
- 3) insert specs about the water heating system: Energy factor of 4, 2 inches of non-CFC foam insulation, 6 80 gallon tanks
- 4) insert specs about the building envelope: 9.75 in. of insulation, R-value of 28.8
- 5) insert specs about plumbing: total pipe length=203.21 ft, farthest distance from water heater=173.21 ft
- 5) insert specs about the building location and orientation: North-south orientation, Address 1546 E 108th Street, Los Angeles CA 90059
- 6) insert specs for the PV system: 46.3 KW
- 7) insert electrical loads for the building
- 8) run program to determine Home Energy Rating Score

Results: HERS score for our building

Test Date(s): 3/4/21-3/11/21

Test Results: 3/18

with PV system: -2 HERS score, without PV system: 46 HERS score. With our PV system our building based on the 2-bedroom unit qualifies as net-zero

Performed By: Erich

Comments: Our project is to design a net-zero apartment complex. The HERS score determines if the building reaches net-zero energy use.

Test Procedure Template

Test Name: Project Budget

Purpose: *The purpose of this test is to calculate the total budget for our attached housing construction. We aim to have a net-zero building that serves the low-income population, so we want to maximize the quality of the building while keeping the budget in mind.*

Scope: This test is to calculate the materials, labor and equipment costs of the construction project. The program will estimate the unit price and assembly and output predictive cost data with the inputted data.

Equipment: Laptop/Desktop

Hazards: N/A – Computer simulation

PPE Requirements: N/A – Computer simulation

Facility: Anywhere with stable internet

Procedure:

- 1) List of types of materials, labor, and equipment
- 2) Itemize by codes within the program
- 3) Create square foot estimates conceptually

Results: Pass Criteria, Fail Criteria

Pass – Under \$4.5 million for construction

Fail – Over \$4.5 million for construction

Test Date(s): 3/4/2021-3/25/2021

Test Results:

	Our Model	Other Affordable Housing Development
Estimated Budget		
Target Budget		

Performed By: Ashley Kim

APPENDIX Y: USER MANUAL

Because the only users for our design are the residents living there and that does not require instructions, we were advised to write a user annual for future teams competing in the Solar Decathlon by our faculty advisor.

Step 1) Assembling a Solar Decathlon team

The Solar Decathlon competition emphasizes the interdisciplinary nature of a successful team. Ideally, a team would have several architecture students, construction management, civil engineers, and mechanical engineers. However, there is no set requirement for how many of each major to include. To be as successful as possible, recruit as many students as you can to your team. Many of the teams that compete are ones that have 20 or more people and have been working on their design for over a year. The more people you have, the more in-depth your design will be. We recommend having at least 4 architecture, 3 engineering, 3 construction management, 1 landscape architecture, 1 structural engineering, and 2 city and regional planning students.

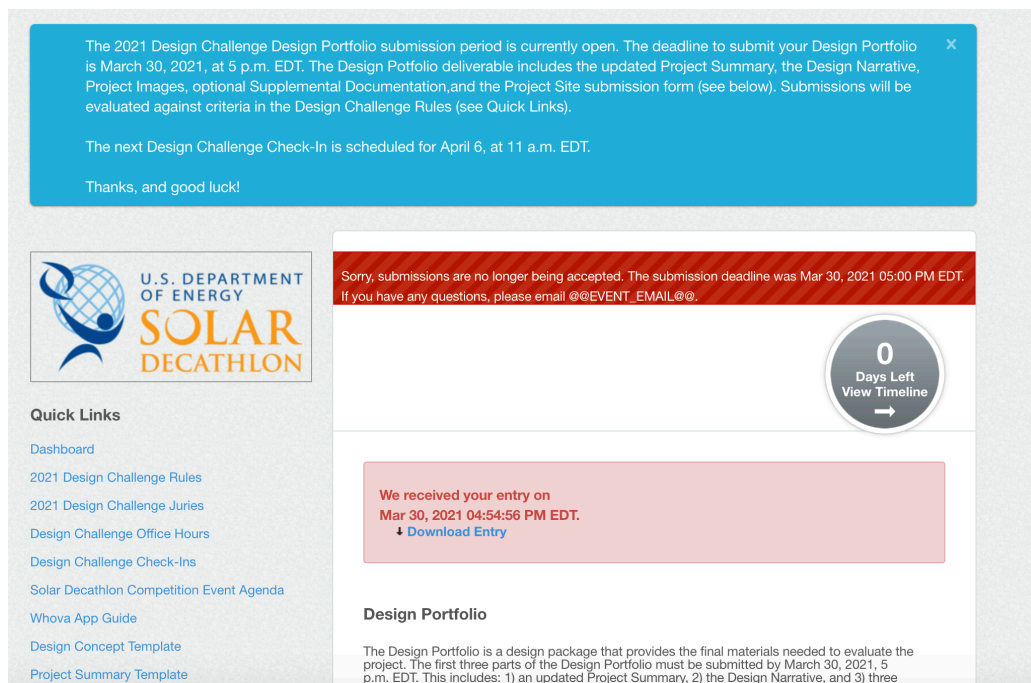


Figure 54. Solar Decathlon portal

Step 2) Selecting a category to compete in

There are seven categories of buildings to potentially compete in: Suburban Single-Family Housing, Urban Single-Family Housing, Attached Housing, Mixed-Use Multifamily Building, Elementary School, Office Building, and Retail Building. There are several factors that might impact your decision to compete in a certain category over another; for example, if you have more than one architecture student competing on the team for independent studio credit, it will be harder for them to receive credit for simpler designs, like single family housing. Select a category that is feasible for the size of your team.

Step 3) Reaching out to industry partners, professional, or professors

We recommend reaching out to individuals who have expertise in the fields involved in the Solar Decathlon. For example, on the mechanical engineering side, we reached out to several professors in the HVAC concentration who were able to connect us with sales engineers to help us select equipment. There are several professors who have competed either in the build competition or the design competition and have information about how the designs are evaluated. To be more successful, we recommend reaching out to these industry or professional partners as early as you can. Connecting with these professionals will provide useful guidance for where your design goes and reduce the amount of time you spend researching.

Step 4) Getting started on the design

The timeline of the competition forces teams to lock certain decisions in early on, which might result in limiting your future options (e.g. it is hard to make space for different equipment requirements when the architectural layout has already been decided). The key to being successful in this competition is to figure out the make-up of your team and the narrative of your design as quickly as possible. We found that a strong narrative and community connection is very important in guiding your design work and in being more effective in the competition. Additionally, it is crucial to make sure that each sub team of the solar decathlon is communicating frequently to minimize parts of your design that clash with one another, like deciding the plenum space in the architectural design without knowing the requirements of the HVAC system.

Step 5) Completing the design

There is several necessary software to complete a successful Solar Decathlon design. Several of these are available through Cal Poly and others are available through the Solar Decathlon (under resources). On the engineering side, we recommend using Helioscope for solar panel layout and modeling, Revit for MEP drawings, Opaque for wall section renderings, One Click LCA for the life cycle cost analysis, REM/RATE for the HERS score evaluation, and either Trace or Design Builder for the HVAC simulation. The images below demonstrate how we used this software in our design. Once the design has been completed, you must produce a Design Portfolio. We recommend using InDesign for compiling this portfolio, with one assigned person to produce the final document for consistency (although it will be a major undertaking for this person).

In completing the design, be as creative as possible with the architecture and engineering. For example, the team that won this past year had a very novel way of heating and cooling their building by utilizing their towns abandoned coal mines as a thermal reservoir. This competition rewards creativity over practicality. We recommend researching novel engineering and architectural designs.

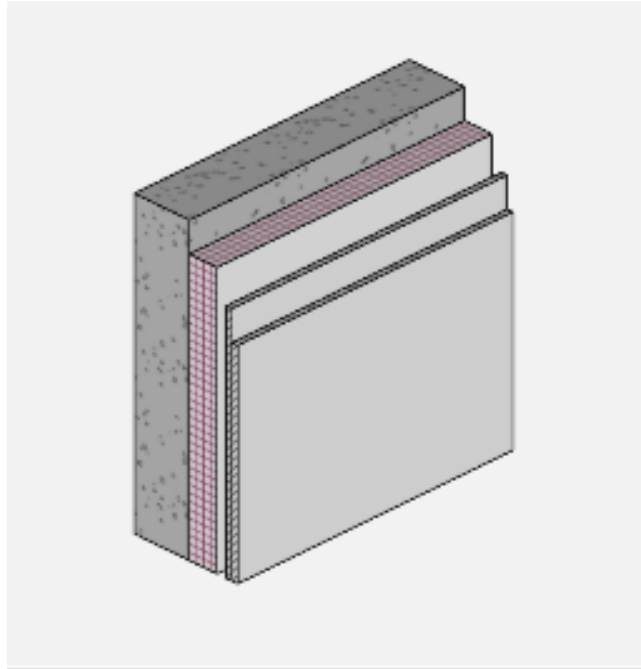


Figure 55. Opaque rendering of wall section

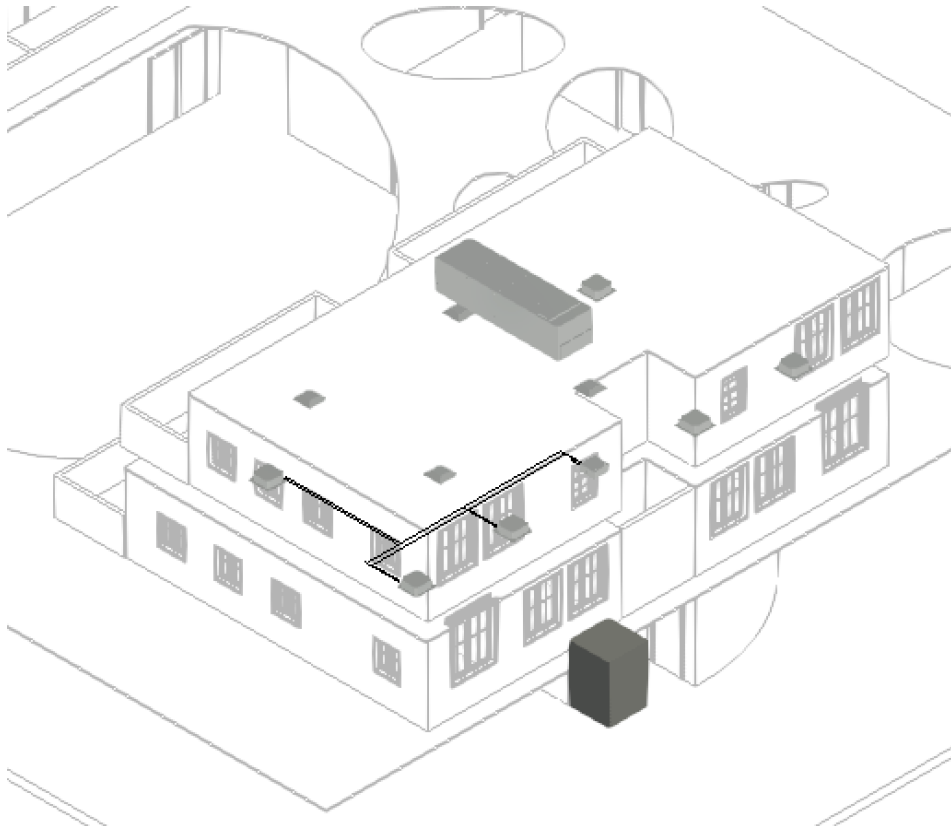


Figure 56. Revit rendering of mechanical layout

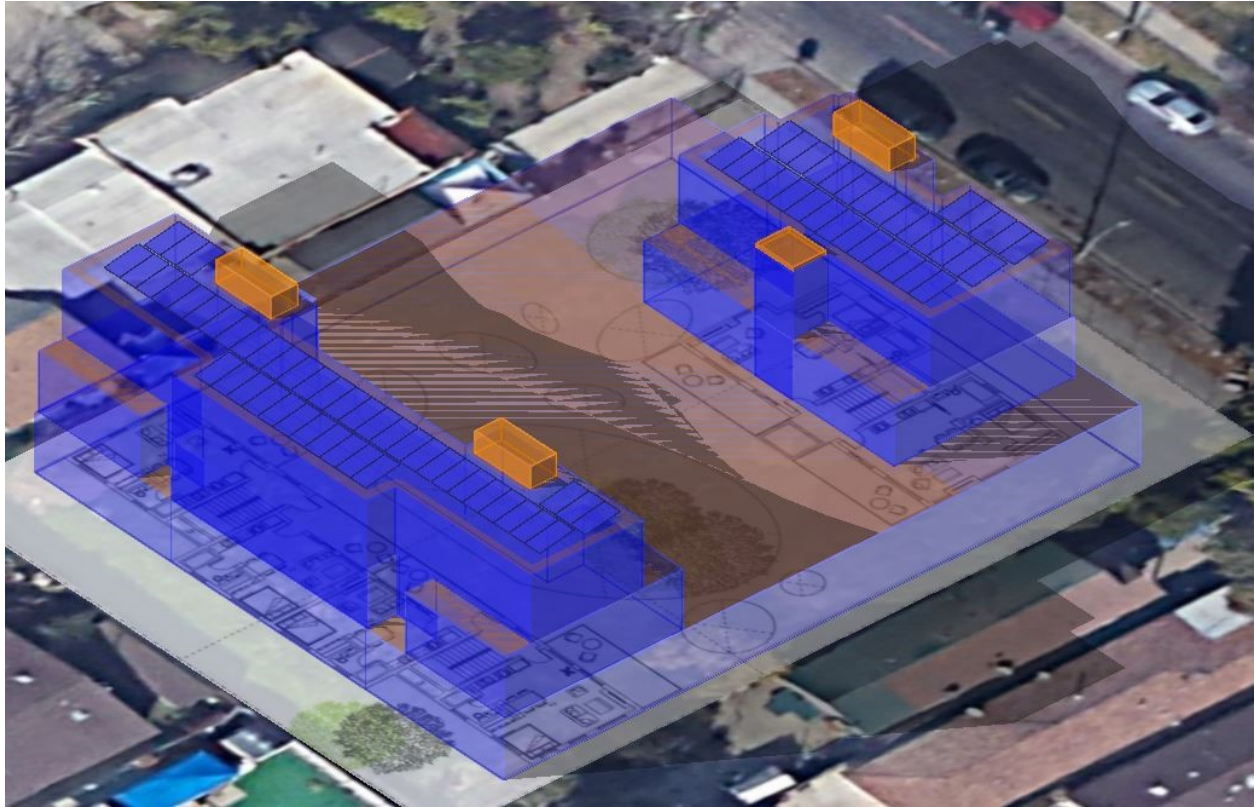


Figure 57. Helioscope for solar planning

Step 6) Competing in the Solar Decathlon

For the Solar Decathlon, it is very important to be aware of the deadlines throughout the competition. Using the OneDrive calendar and having a team lead that continuously reminded the rest of the team of these important dates worked for our team. For the submissions, especially for the design narrative, starting at least a couple of weeks before the submission date is recommended. Make sure you leave enough time to make your documents cohesive rather than segmented due to each team member's writing style. The competition weekend involves a live presentation with a Q&A afterwards with jurors. They will evaluate the design based on ten competitions and assign winners in each category as well as a grand residential winner and grant commercial winner.